DEVELOPMENT OF A LOW COST BIPOLAR CURRENT DRIVER FOR HYBRID STEPPER MOTOR APPLIED TO MOTION CONTROL

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***Abstract* - The present work deals with the project and construction of a low cost bipolar current driver, based on the integrated circuit L6208N to start hybrid stepper motor. The largest contribution of this project is the increase of current in each phase of the motor by a factor of 3, which was achieved by the development of a special heatsink, different from the manufacturer's orientation for this integrated circuit. This allows the driver to control a stepper with higher power. The second contribution of this project is the additional circuit to L6208N that supplies an external signal indicating if the driver is activated or disabled by an internal or external protection. This external signal can avoid damage on the product that is being manufactured and/or tools of the automated machines that operate with more than one joint. The third contribution is a circuit that reduces the current reference value of the driver when the stepper motor is stopped. This strategy reduces Joule effect losses of the starting system, motor and driver. The last contribution is the development of an additional circuit to L6208N that generates the "step" and "dir" commands. This circuit is important because it generates the signal for the motor to work. Therefore, in situations where the controller is not installed or disabled, it can put the stepper motor in operation with the objective of evaluating the mechanical status of a machine before it enters in automatic operation. A 60W prototype was built in order to validate the concepts employed in the project of the driver. Following, the practical results are presented.**

***Keywords* – bipolar starter, current driver, stepper motor, integrated circuit L6208N.**

I. INTRODUCTION

Automated equipments that need movement, positioning and speed control, such as industrial robots and machines that use computer numeric control can be controlled electrically by the following technologies: stepper motors, DC motors (with brushes) and servo brushless motors DC or AC. Although none of these technologies is ideal, in other words, each one presents a series of advantages and disadvantages.

The hybrid stepper motor is the solution that presents low cost, no maintenance, is stable when stopped and simpler electric installation. As disadvantage it presents position loss not detected in open loop, when stopped consumes energy and it presents an excessive electromagnetic loss in high-speeds [1]. This motor type can be started by imposing voltage or current in their windings, in one or in both directions, characterizing respectively, a unipolar or a bipolar driver. The bipolar driver that imposes current in the winding, compared with the other three types of driver, renders a higher torque and a larger speed range to the stepper motor [1].

The starter performance of certain revolute joints or prismatic joints in automated machines depends on the characteristics of all the elements that compose the control motion system, in open or closed loop control, according to Figure 1.

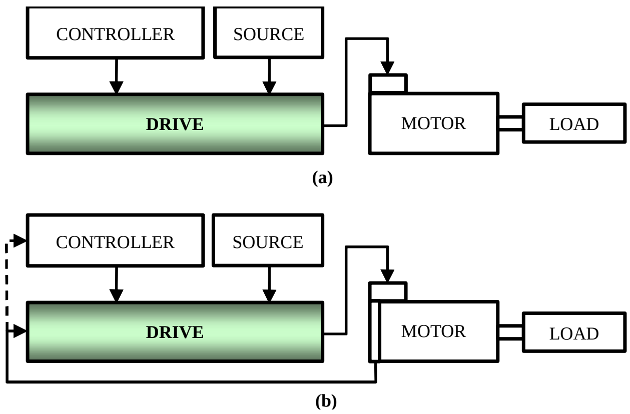

Fig. 1. Elements of a motion control system in open loop (a) and in closed loop (b).

In the feedback loop of the motion control shown in the Figure 1.b, the motor becomes a servomotor for incorporating a sensor of position and speed in its axis. The closed loop of motion control can be accomplished by two ways. The first is through the driver (called now servo driver) assuming the function of controller in the system. In this case the user just supplies the reference values. The second is to accomplish the control loop through an external controller (which is the classic way), where the driver just has the function of power amplifier. Both ways to accomplish the feedback loop imply a higher cost and more complex installations.

The loads nature defines its needs, such as torque, speed and acceleration will select the technology to be used and the type of motion control: with or without position and speed feedback. Usually, many situations are solved perfectly with the actuation of the hybrid stepper motor in open loop [2].

II. DRIVER DESCRIPTION

The developed product is based on the integrated circuit L6208N according to the simplified block diagram shown in Figure 2. This component is applied in the bi-directional starter in current of stepper motors and it was chosen in this development because of its characteristics: supply voltage between 8 and 60 V, adjustable effective current from 0 to 2.8 A per phase, switching frequency up to 100 kHz, two bridges of mosfet transistors (RDS(on) = 0,3Ω), internal protection of overcurrent, temperature and subvoltage, digital command (TTL) of the step and direction, choices of half-step, full-step or micro-step operation, bi-directional inhibition signal, configurable current slew-rate and a low cost if compared to other solutions [3].

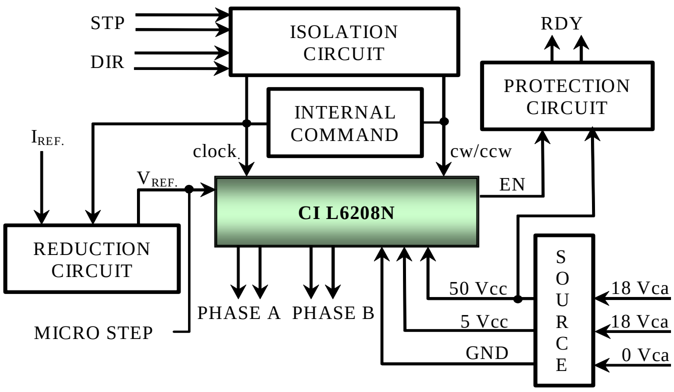

Fig. 2. Basic diagram of the driver.

The source power of the developed driver is made in monophase alternating current, ±18V with medium point, which results in a DC link to 50 V. This high voltage, near the limit of L6208N makes possible the operation in a wide range of speed.

The protection against high voltage acts when the voltage in DC link crosses the limit (52 V). In this condition the DC link is short-circuited by a thyristor rupturing the input fuse. The source also supplies a regulated continuous voltage of 5V to supply signals and control commands to the L6208N.

Although the manufacturer describes the component L6208N, shown in the Figure 3, as a complete integrated circuit for control of stepper motor, it needs some technological adaptation aiming to increase its performance, protection and flexibility. Those improvements are the goals of this project and they are detailed as follows.

The L6208N has a PDIP-24 pin package where the central pins (6, 7, 18 and 19) besides being connected to the terminal GND of the source are used to transmit heat from the component to a copper area on the printed circuit board. That copper area is recommended by the manufacturer to be constructed in the top layer or bottom layer and has the function of dissipating the heat generated in the L6208N.

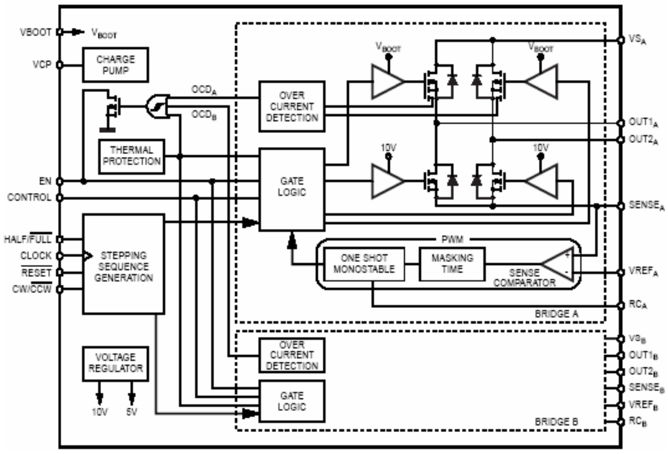

Fig. 3. Block diagram of the L6208N [3].

The graph shown in Figure 4 shows the behavior of the thermal resistance of the junction-atmosphere (Rja) according to the copper area of the printed circuit board. This graph shows that the thermal junction-ambient resistance tends to be constant and has a high value, around 39 ºC/W on the top layer and 42 ºC/W on the bottom layer of the PCB, even with the increase of the copper area. This dissipation problem limits the value of current (rms) per phase in only 0.93 A [4].

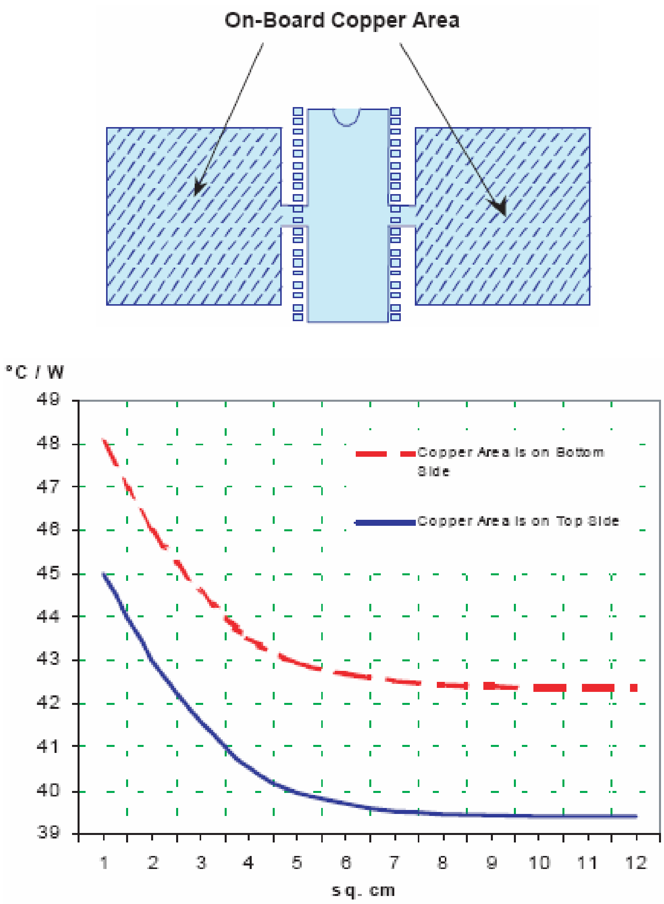

Fig. 4. Thermal resistance between junction-atmosphere in function of the copper area on the printed circuit board [3].

With the project and construction of the special heatsink of approximately 60 grams and 8.4ºC/W thermal resistance shown in Figure 5, the integrated circuit L6208N could supply the maximum RMS current per phase (2.8 A/phase).

The radiator made of aluminum has a cylindrical shape and it is constituted of ten circular fins. The union part is made of brass with a hexagonal shape. The attachment among the elements, shown in Figure 6, is the following: CI L6208N is a soldier with a lead-tin league to the union piece while the radiator is screwed on to the union part.

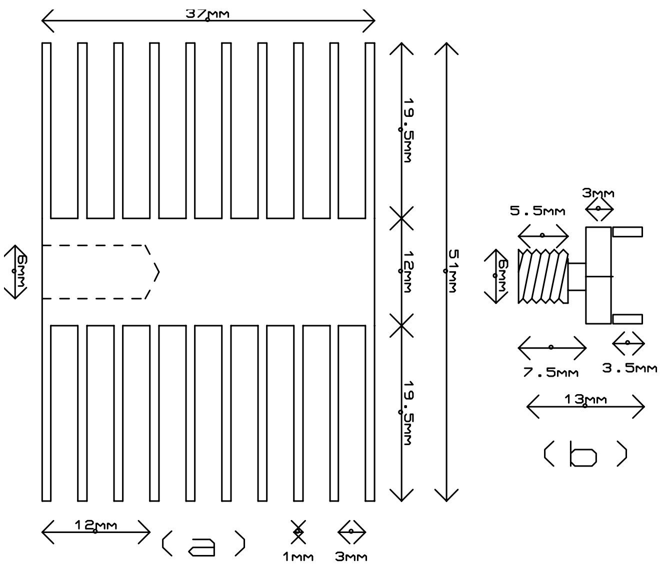

Fig. 5. Project of a heatsink. In (a), the heatsink and in (b), the union part between L6208N and the heatsink.


Fig. 6. Heatsink developed for L6208N.

A circuit for additional protection was developed (shown in Figure 7) with the objective of avoiding damage to the product that are being manufactured and/or tools of the automated machines that operate with more than one motion joint. The CI L6208N has an enable pin (named EN), and the logical low level on this pin inhibits the activation of all power transistors of the two internal bridges.

The components R11 and C1 have the function of enabling CI L6208N and to start the relay RL that, through its contacts, signals that the driver is active (through the green led L2) and it informs the interchange circuit of the system, through the contact RDY, that the respective motion joint is in operating state.

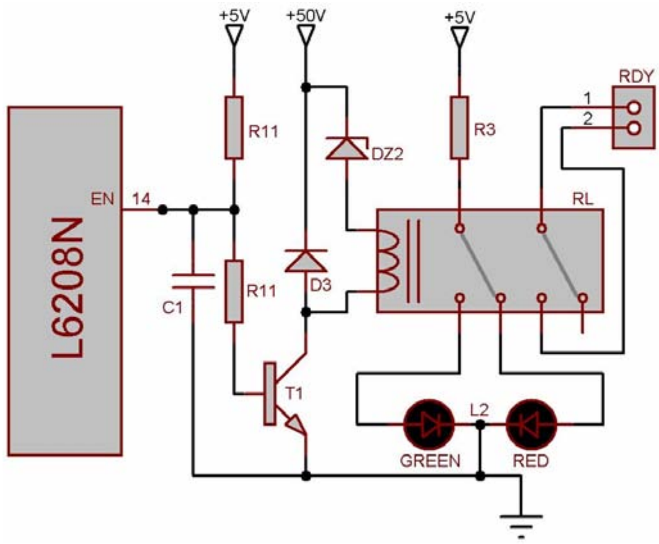

Fig. 7. Aditional circuit to protect L6208N.

When the internal protection of the CI L6208N occurs (temperature or overcurrent), the enable signal EN reaches low logical level turning off the relay RL. The relay contacts show that the driver is disabled (through the red led L2) and informs the machine control system that the respective joint is inoperative through the contact RDY. When a subvoltage happens in the power source, that is, voltage below the Zener diode voltage DZ2 (24 V), the relay RL is turned off. In these two cases, the interchange circuit interrupts the power source for to all the drivers on the machine and consequently stops its movements.

A circuit to enable the step (CLOCK) and direction (CW/CCW) signals was developed (see Figure 8). These signals can be supplied by an internal or external circuit to the driver, in agreement with the position of jumper J1.

The internal command option (CI) has two functions: change the speed value of the stepper motor (through the potentiometer P2), and modify the motor rotation direction by selecting one of the three positions key SWITCH. This internal command circuit is fundamental in situations where the controller is not installed or disabled and when one has the need to evaluate the mechanical part of the control system.

In the external command option (CE), the external step (PAS) and direction (DIR) signals are isolated through a high-speed optocoupler 6N137. This circuit provides the galvanic isolation between the controller and the driver and it still allows choosing the control logic between NPN and PNP [5].

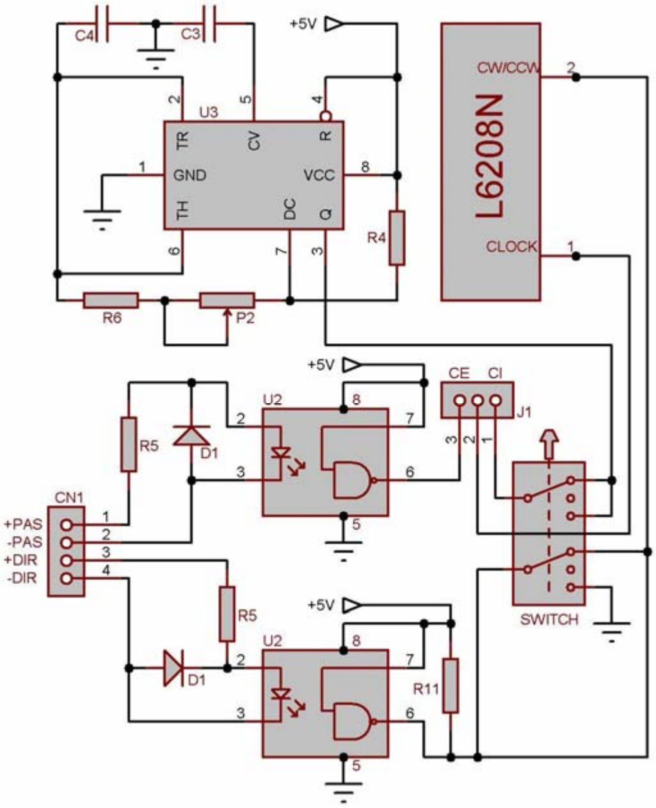

Fig.8 Circuits for enabling internal or external signals of step and direction.

A circuit for automatic reduction of current of the motor was implemented (Figure 9) with the purpose to decrease, in approximately 40%, the value of current supplied by the drive to the motor when it is stopped.

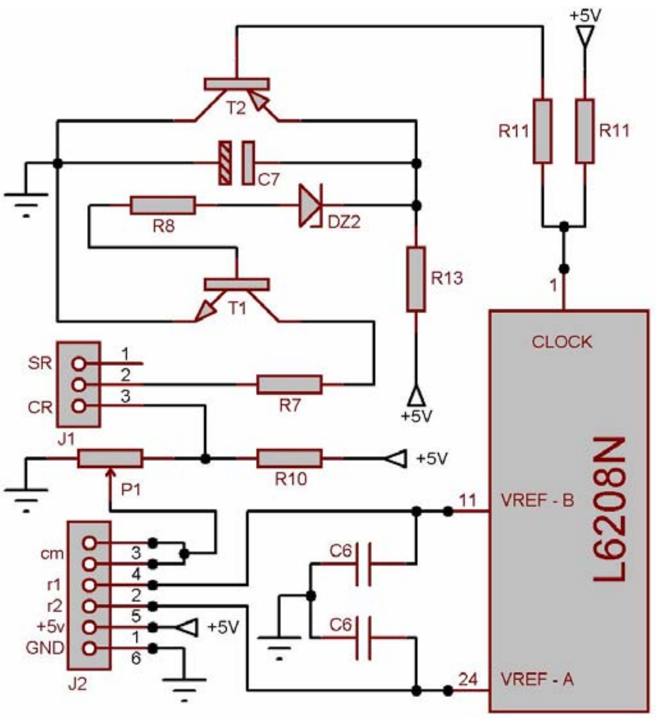

Fig.9 Circuit for automatic current reduction of the motor.

The voltage value between 0 and 1V in the pins VREF-A and VREF-B of L6208N establish, respectively, the value of rms current between 0 and 2.8A, in the phases A and B of the stepper motor. These pins are connected to the J2 connector, and it has two functions. The first is to connect to a circuit of external command to operate the driver in the micro-step mode. The second is to connect internally, through jumpers, these pins to the center of the potentiometer P1 with the objective of adjusting, in the half and full step mode, the nominal current of the motor that it is connected to the driver.

The current reduction of the stepper motor is enabled when the J1 jumper is in the CR position, the terminals 2 to 5 of the connector J2 are short circuited (driver operating in half step or full step) and not command (CLOCK) happens for more than 1s (indicating that the stepper motor is stopped). In this case, the Joule effect losses in the stepper motor and in the driver are reduced sensibly.

III. EXPERIMENTAL RESULTS

The initial prototype shown on figure 10 was built with a bipolar current driver to start the hybrid stepper. It has the following dimensions: 110 mm length, 76 mm width and 58 mm height. The projected electronic board made for this driver has only one layer and uses electronic components with PTH technology.

Fig 10. Developed prototype.

Several tests were accomplished to evaluate the performance of the driver including the technological adaptations proposed in this project.

The first experiment intended to validate the heatsink project by keeping the driver with nominal rms current for two hours. In this situation, the internal protection of temperature of the L6208N, adjusted by the manufacturer in 165ºC didn't act, indicating that the heatsink is correctly projected. The maximum temperature registered in this heatsink was 85ºC.

The second experiment aimed to validate the circuit of the additional internal protection against excess of temperature. In this case the driver was imposed with nominal rms current without the heatsink.

After a certain time the internal protection on temperature acts by disabling the command of L6208N through the signal EN shown in the upper curve of Figure 11. With that, the relay RL is turned off interrupting the power to the driver through the RDY contact. With fast cooling, the L6208N is enabled by a short period of time, consuming the energy of the DC link (see bottom curve of Figure 11). The DC link voltage finally drops disabling the driver and showing this action by turning on the red led.

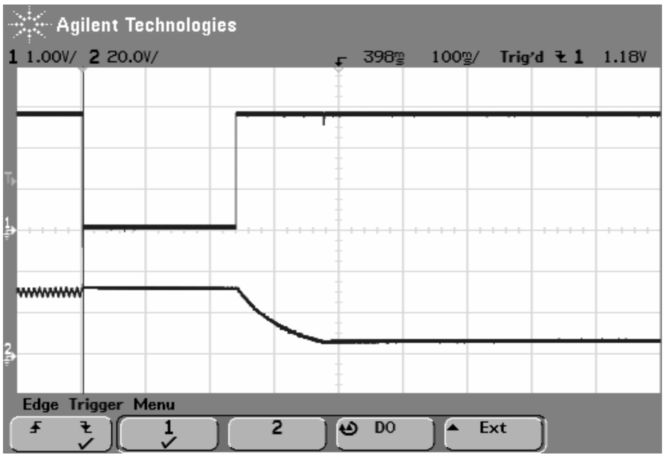

Fig. 11. Performance of the protection circuit against temperature above limit (CH1: 1 V/DIV, CH2: 20 V/DIV e BT: 100 ms)

In the third experiment the current reduction circuit of the stepper motor was evaluated when stopped. In this case the stepper motor worked with a clock of 0.38 Hz (upper curve of the Figure 12). Observe that after 1.8 s the first command pulse occurs there is a reduction of approximately 40% of the value in the current reference in each phase of the motor (signs VREF-A and VREF-B, as it indicates the bottom curve of the Figure 12).

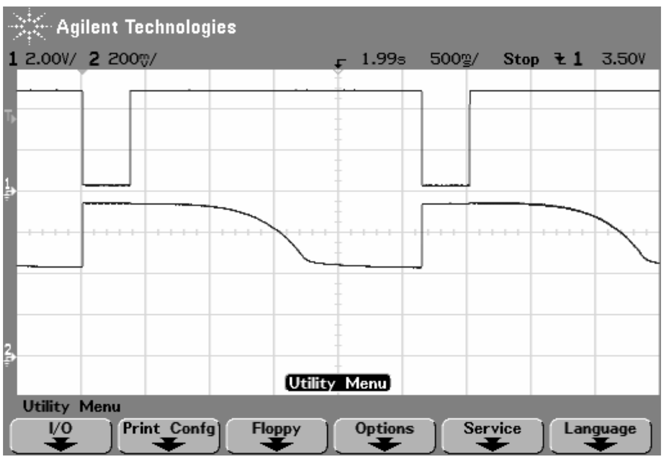

Fig. 12. Current reduction of motor. (CH1: 2 V/DIV, CH2: 200 mV/DIV e BT: 500 ms)

In the last experiment (Figure 13), the driver was configured to half-step mode with a hybrid stepper motor of 1.2 A per phase (two phases) and DC link voltage of 50V. The objective of this experiment is to verify the variation of rms current in each phase of the motor, in other words, the torque in function of the axis speed. Although the graph of Figure 13 presents a range of speed of 900 rpm (6 kpps), this stepper motor was acted, in both direction rotation, until the frequency of the 10 kHz (1500 rpm) without load.

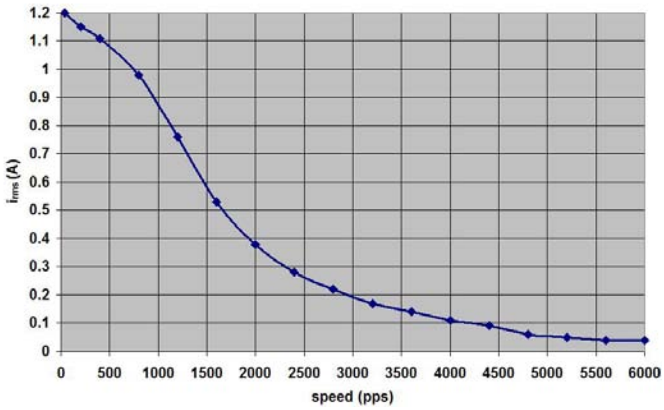

Fig. 13. Graph of rms current per phase versus velocity in pulse per second (pps).

IV. CONCLUSION

The initial prototype of the bipolar driver in current was tested in extreme situations of acting of hybrid stepper motors being shown flexible, robust and with good performance.

The driver presented in this article is compact, easy to operate, reliable and now it has the best cost-benefit in terms of starting hybrid stepper motor.

The characteristics mentioned above provide to this driver the application for the teaching area at the Industrial Automation High Level Course of CEFET/SC as in the area of starting automated machines in the industry.

Besides providing to the integrated circuit L6208N an increase of the current of each phase for a factor of 3, this heatsink has the advantage of uncoupling the thermal dissipation of this component from its printed circuit board, becoming more compact.

Good results were obtained in the circuits of additional protection and current reduction, which provide, respectively, safe operation of the automated machines with more than one motor joint and reduction of Joule effect losses in the motor and in the driver.

ACKNOWLEDGEMENT

The authors thank the collaboration of teachers Felicio José Gesser and Vilmar Coelho in the development of this equipment and to CEFET/SC for the financial support.

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