APPLICATION OF A BUCK-TYPE MC2 REGULATED CONVERTER FOR A STEPPER MOTOR CONTROL

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In this paper, a stepper motor control using twin bidirectional buck converters is presented. The system can be split in two in the following way :

- digital electronics for the generation of sine reference voltages with variable frequency,
- analog electronics being two buck regulators, each followed by an inverter bridge that drive the stepper motor.

The sine reference with variable frequency is used to avoid vibrations on the motor axis. The digital circuit outputs its data via a D/A converter that gives the rectified value and sign of the sinusoidal signals to the buck converters of the analog part and bridge-inverter which allows for a bipolar motor current.

Keywords : Antenna Pointing Mechanism, stepper motor, (microstep) motor control, bridge-inverter.

1. INTRODUCTION

Traditional stepper-motor control can produce unacceptable vibrations. The use of micro-steps eliminates this problem and makes the control comparable to that of a synchronous motor. The example here presented is an application of this principle used to control the two motors of a two-axis antenna pointing mechanism. In this case, we do not only consider the problem of vibrations, but also a control-law that must be compatible with the stability of a satellite.

In this article we present the conception of :

- the digital part that produces sine references that follow such a control-law,
- the analog module which generates the motor-currents that follow the sinusoidal references, independently of the satellites bus voltage.

Together with an internal power supply, an interface to a central computer and some additional functions they form the following block diagram (Fig. 1).

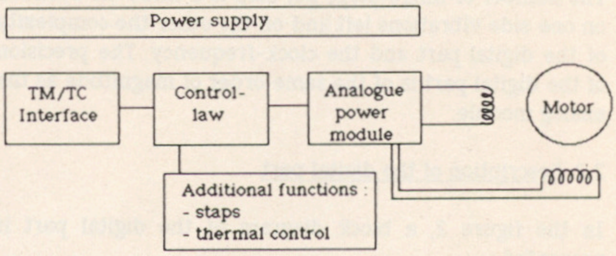

Figure 1. System block diagram

2. DEFINITION OF THE DIGITAL PART

2.1. The control-law

Each motor drives an axis with a reducing gearbox having a good precision (a few minutes, typically) and a long life time (> 10 years). A simulation of the structure and vibrations in the system for a medium speed movement have confirmed the choice of the reducing gearbox and motor (Ref. 1).

$$C_o \sin M(x - \emptyset) = J_m \frac{d^2\emptyset}{dt^2} + \frac{k\, d\emptyset}{dt} + \frac{R}{r} \cdot \frac{(\emptyset - q)}{r} \quad [1]$$

$$(\emptyset - q)\, R = J_c \frac{d^2 q}{dt^2} \quad [2]$$

System equations

with :
- x angle of the magnetic field (micro step to step)
- $\emptyset$ angle of the axis
- q angle after reduction
- R rigidity of the connection
- r factor of reduction
- J_c load inertia
- J_m inertia on the motor axis

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The results of different control-laws have been calculated using a dynamical model of the motor with its electrical time constant, its damping ratio and hysteresis, the reducing gearbox with linear friction and a load representing the inertia of the antenna.

The main results were :

- Control of the motor step-by-step introduces accelerations that are unacceptable (> 1k rad/s^2).
- Control with constant speed produces better results, but the accelerations at the beginning and end of the movement are still too high.
- The best results are obtained using a so-called Bang-Bang algorithm with constant acceleration and deceleration. Vibrations are reduced to less than 10 %.
- Complicated control-laws do not reduce vibrations significantly.

The resulting vibrations depend largely on the precision with which the control-law (double parabola) is followed. The number of micro-steps per step is a trade-off between on one side vibrations left and on the other the complexity of the digital part and the clock-frequency. The precision of the digital part is of the same order of magnitude as the analog module.

2.2. Description of the digital part

In the figure 2, a block diagram of the digital part is presented :

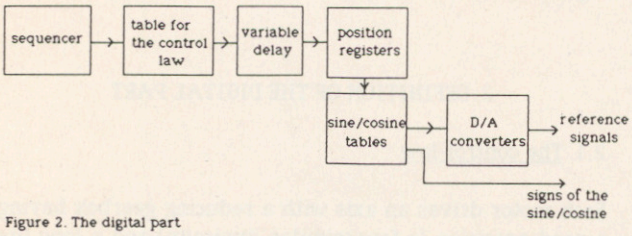

Figure 2. The digital part

For each movement, the sequencer generates an index to the table for the control-law. This table holds the delays between the increments of the position registers. The reference signals are calculated with a sine/cosine table. Finaly, D/A converters are used to provide the analog part with its reference signals : a sine and a cosine for the respective windings of the motor.

3. DEFINITION OF THE ANALOG PART

The currents in the two windings of the motor follow the sine and cosine references. These waveforms must be respected because their relative value corresponds to the angle of the magnetic field in the motor. An error in the amplitude may lead to a variation of the couple, but will not lead to an error in the position, as long as the sine/cosine ratio is maintained. This enables the use of a "reduced power mode" when the motor becomes too hot. Realisation of symmetrical sine/cosine currents requires either a Push-Pull with a bipolar power supply or an H-bridge inverter. Despite the greater complexity of the H-bridge, we have selected this solution, because it enables the use of the bus of a satellite as supply. The transistors of the bridge are controlled by the sign of the sine resp. cosine, which are supplied by the digital part. The amplitude is modulated by a buck type converter which uses the motor as inductor.

The figure 3 summarizes the design.

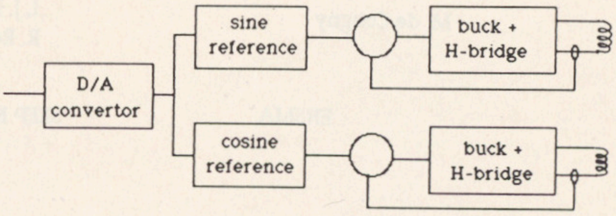

Figure 3. The analog power module

In this case, the bidirectional buck converters are current-controlled by a MC^2 current loop. The choice of a bidirectional converter can be explained by their better control of the motor current without passing to discontinuous conduction mode (Ref. 2,3). The MC^2 control of the buck works excellently. The H-bridge, however, does not. The Buck applies alternatively Vbus (the voltage satellite bus) and 0V to the bridge, while the bridge tries to keep two transistors saturated and the other two blocked. Here, we do not only have the classical problems of the H-bridge (cross conduction peak voltages caused by chopping the motor current) but also the problems caused by the transitions Vbus-0 V and 0 V-Vbus. Especially the 0 V-Vbus transitions caused the transistors, which are normaly blocked, to conduct for several micro-seconds. This phenomenam has been revealed by means of simulation. The simulations have also enabled the realisation of a control circuit that does not have those problems (Fig. 4). Tests have shown that the buck-bridge combination is able to follow the reference signals satisfactory (Fig. 5).

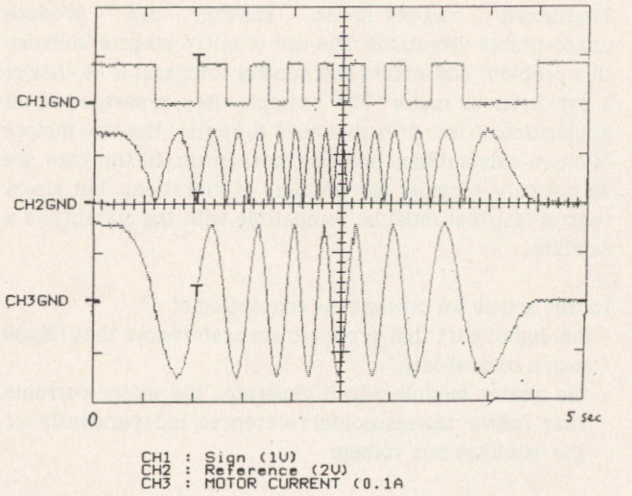

Figure 5. Sign, reference and motor current.

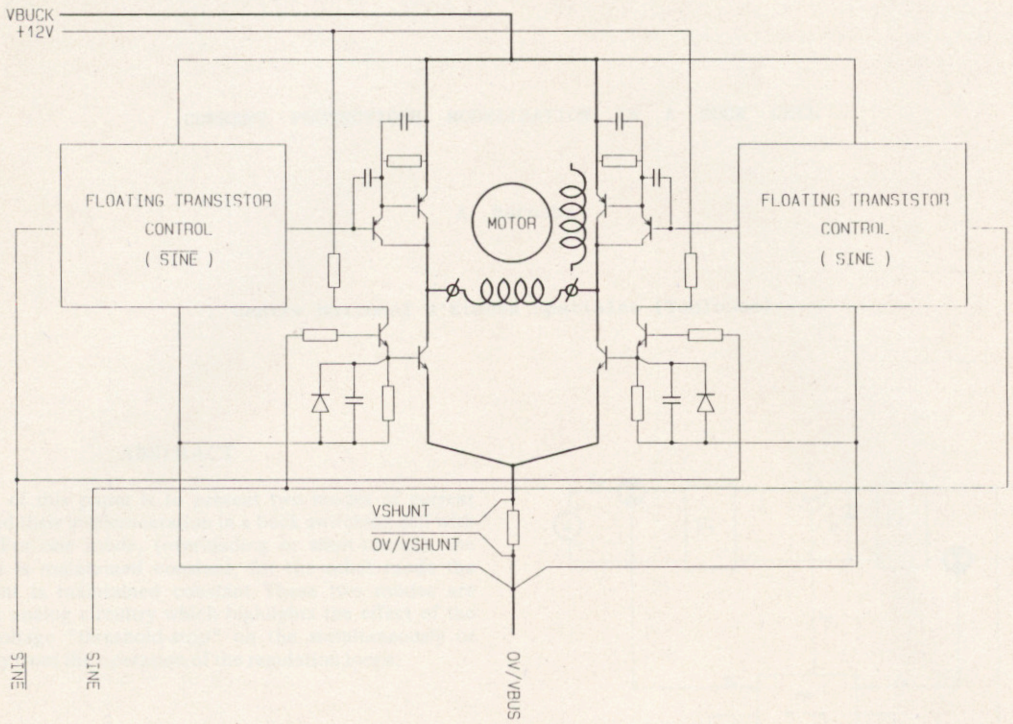

Figure 4 - Bridge-Inverter

4. CONCLUSION

The control of stepper motors using current feed-back and an H-bridge is particularly interesting for applications where the vibrations introduced by step by step motor control are unacceptable. The prototype is under test at Alcatel Espace and meets its specifications. The principle can be also used for high-precision control of stepper motors.

N.B. : Patents pending on
- control law and its realisation
- analog part.

5. REFERENCES

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