DSP IMPLEMENTATION TO THE DRIVE AND POSITIONING CONTROL OF BEARINGLESS MACHINE

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Abstract – **This paper describes the initial stage of the study and a DSP application for the drive and positioning control of a three-phase bearingless induction machine, with four poles and 250W of power using the TMS320LF2407A DSP of Texas Instruments Inc®. This study check its considerable versatility and high processing speed.**

KEYWORDS

DSP, digital control, bearigless and induction machine.

I. INTRODUCTION

This work shows a bearingless induction machine which presents its control system implemented on a *Digital Sign Processor*. The utilization of a bearingless machine can be necessary and beneficial when some system has accessibility problems or extreme bearing consuming. The induction machine was choosen because the low cost. The fields responsible by the toque generation also are used to provide the rotor positioning control which should have fast response and hi precision. Because this, the DSP was requested.

Among the several types of electric machines that can be controlled by DSP, the bearingless machine is a special motor type that has as operation behavior the axis magnetic levitation, through the control of the stator currents. For drive and control, the system needs of several DSP available resources. This work began with a research with different DSPs models and manufacturers.

The DSP is consolidating as one of the most versatile and fast devices for electric machines drive and control. Added to the high-speed processing, they have resources as: event manager modules, analog-to-digital converter (ADC), serial communications interface (SCI), serial peripheral interface (SPI), watchdog timer and general-purpose bi-directional digital I/O pins (GPIO), which are used as PWM channels.

The chosen DSP for the bearingless machine drive and control position was the TMS320LF2407A of Texas Instruments Inc®[1], due to this to dispose of all the necessary hardware resources to the control software development.

Another potentiality of DSPs is the implementation of the control techniques based on artificial intelligence as: Fuzzy Logic controllers, Neural Network and Fuzzy-Neural controllers. These modern controllers should be applied to non-linear systems control. The bearingless machine presents non-linearities under certain operating conditions, needing, like this, of the use these controllers to compensate possible classic controllers deficiencies.
This work describes the initial stage of the study and implementation for the drive and positioning control of a three-phase bearingless machine using the TMS320LF2407A DSP of Texas Instruments Inc.

III. DESCRIPTION OF THE SYSTEM

The studied bearingless machine is a conventional induction machine with four poles and 250W of power. It is adapted to work without its mechanical bearings and its radial positioning is controlled by magnetic fields [2]. The machine has a fixed stator on a base, which holds a free rotor to move itself in the horizontal direction in the top, and its bottom is limited by a bearing. The machine is in the vertical position to facilitate the control, this way it is not necessary to compensate the weight force [3].

The arrangement sown in the Fig. 1 allows a phase current pondered division. When occur a rotor displacement in some direction the current in the divided windings of the same phase is unequal, it is increasing in a part and decreasing in the opposite part because the windings are located symmetrically with regard to the rotor. This way the control acts to amplify the force in higher air gap direction and to reduce the force in the opposite direction but always is kept the current nominal value in current sum in the same phase windings in order to the rotating field do not be perturbed.

The Fig.2 shows the system block diagram with the windings divided. The system informs continuously to controller the rotor position, **X** and **Y**. Those values are compared with values that depends the machine dimensions. To enable this control it is necessary that the each half-phase winding be controlled individually. Then, it is used six inverters where there is the liability to keep the currents balanced in each phase although the inverters are supplied individually. When there is a current increasing in the half winding in the

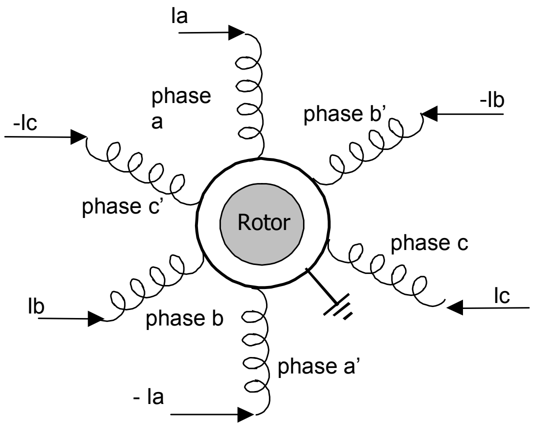

Fig.1: Stator Windings.

opposite winding necessarily there is a current decreasing to keep the torque constant and the system balanced [4].

Analyzing the position measurement **X** and **Y** from the position sensors is obtained a position error value comparing with reference values.This error value is PD position control input that outputs the current variation Δ**i** necessary to rotor positioning. It is necessary independent information for each axe (**X** e **Y**), so it is used two controllers. The current variation that locates correctly the rotor in axe **X** is done by phase **A** which receive two different signs, one that supplies half winding plus the current variation (**I** + Δ**i**) and another that supplies the other half winding minus the same current variation (**I** - Δ**i**). A half winding amplifies the torque proportional to increase Δ**i** and the other half winding reduce it in the same ratio, so it is reached to keep the same torque.

The same thing occurs with the others two phases however they are combined to correct the position error in the axe **Y**. The current values from the PD controllers are values that correspond to the sinusoidal sign amplitudes that supply each phase. The generated amplitude to the axe **X** positioning is done by phase **A** while the responsible by the axe **Y** are the phases **B** e **C** this way occurs a positioning force decomposition in axe **Y** in two ones, where each component is kept under control by one of phases (**B** e **C**). All of signs have the same information of frequency that is possible to modify. The phase is the same to the windings in the same axe and unbalanced 120^0 when in different axe to keep balanced the tree-phase system.

II. DSP DESCRIPTION AND PROGRAMMING

For the purpose of this work, the target board that is being used is a Spectrum Digital eZdsp LF2407A. It features a TMS320LF2407A processor from Texas Instruments Inc., operating at 40MHz, as well as 64K words of on-board zero wait-state memory (split between program and data space), embedded IEEE 1149.1 JTAG scan controller and expansion connectors for custom user logic [1]. Since the project is in its initial phase, the target board is still communicating to a PC via parallel port, for debugging and algorithm development purposes. But a future improvement is, certainly, to make the system stand alone, considering the fact that the processor contains some Flash EEPROM memory.

The TMS320LF2407A processor is a 16-bit fixed point DSP based on a modified harvard architecture, which means that it supports separate bus structures for both program and data space [5]. This allows simultaneous access to program instructions and data, and then several operations can be

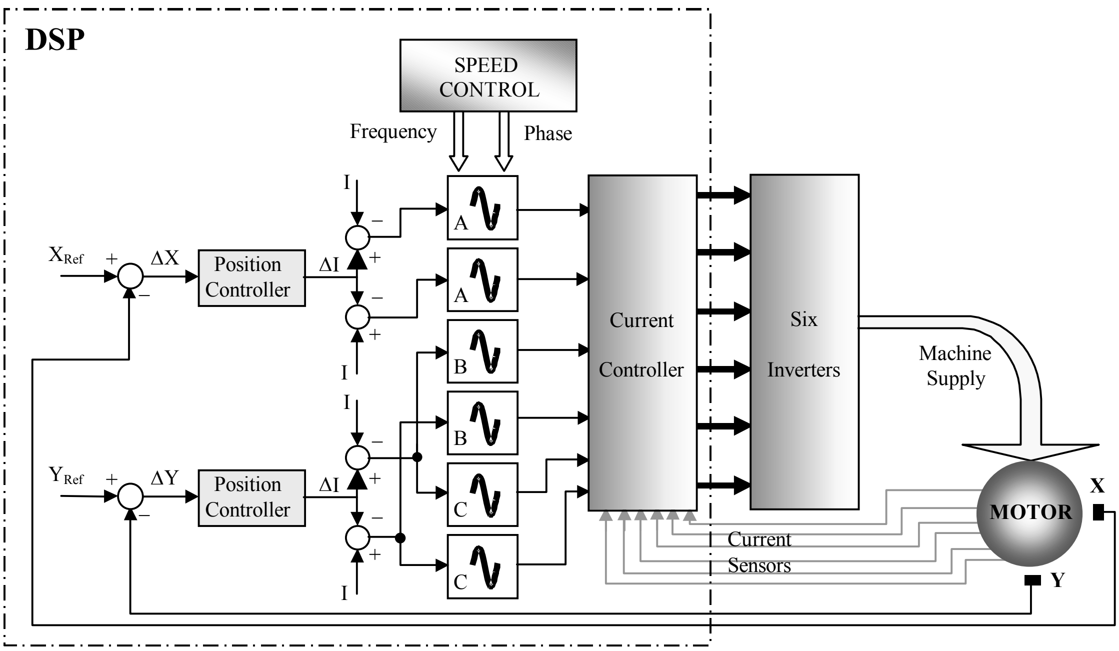

Figure 2: Control block diagram.

performed on a single machine cycle. This DSP also has control mechanisms to deal with interrupts and subroutine calls.

The 2407A contains two types of on-chip memory. The first one is Data/Program RAM (2.5K words), that can be divided between 544 words of Dual-access RAM (DARAM), which means it can be accessed twice per machine cycle, improving the speed of the CPU, and 2K words of Single-Access RAM (SARAM). The second one is the Flash EEPROM (32K words), which stands for Electrically Erasable and Programmable Read Only Memory, meaning it is a nonvolatile type of memory. This feature allows the system controlled by the DSP to stand alone, because once the program is recorded in the Flash memory, the system doesn't need to communicate to the computer anymore.

The TMS320LF2407A features a set of on-chip peripherals that makes it very useful for the purpose of this work. This set includes two event manager modules, an analog-to-digital converter (ADC), a serial communications interface (SCI), a serial peripheral interface (SPI), a watchdog timer and general-purpose bi-directional digital I/O pins (GPIO), to name a few. Those ones that have been used on this work are briefly described next.

The two event manager modules are optimized for digital motor control and power conversion applications. Each module have two general-purpose timers, and provide several functions like pulse-width modulation (PWM) circuits that include dead-band generation units, synchronized A/D conversion and space vector PWM. These circuits can generate asymmetric and/or symmetric PWM waveforms.

The 10-bit analog-to-digital converter (ADC) has 16 channels of analog input. It includes two independent 8-state sequencers that can operate individually or cascaded together into a 16-state sequencer. It is capable to perform 16 auto conversions on a single conversion session, without causing any overhead to the CPU, and it takes at least 375 ns to perform a conversion. In this work, six ADC inputs are being used by the current controller to capture the current sensors outputs, and two more by the position controller to capture the references for X and Y axes.

There are 40 GPIO pins; each one of them is individually programmable to perform its primary function (the PWM outputs are included in this case) or to behave like a regular GPIO (in this case, the pin can work as input or output). All of these modules, as well as their functions can be controlled by configuring several 16-bit registers, and this is basically what the TMS320LF2407A programming is all about.

Fig.3 shows the fluxogram of the program. For the currents of stator windings, there are six proportional controlers running independently.

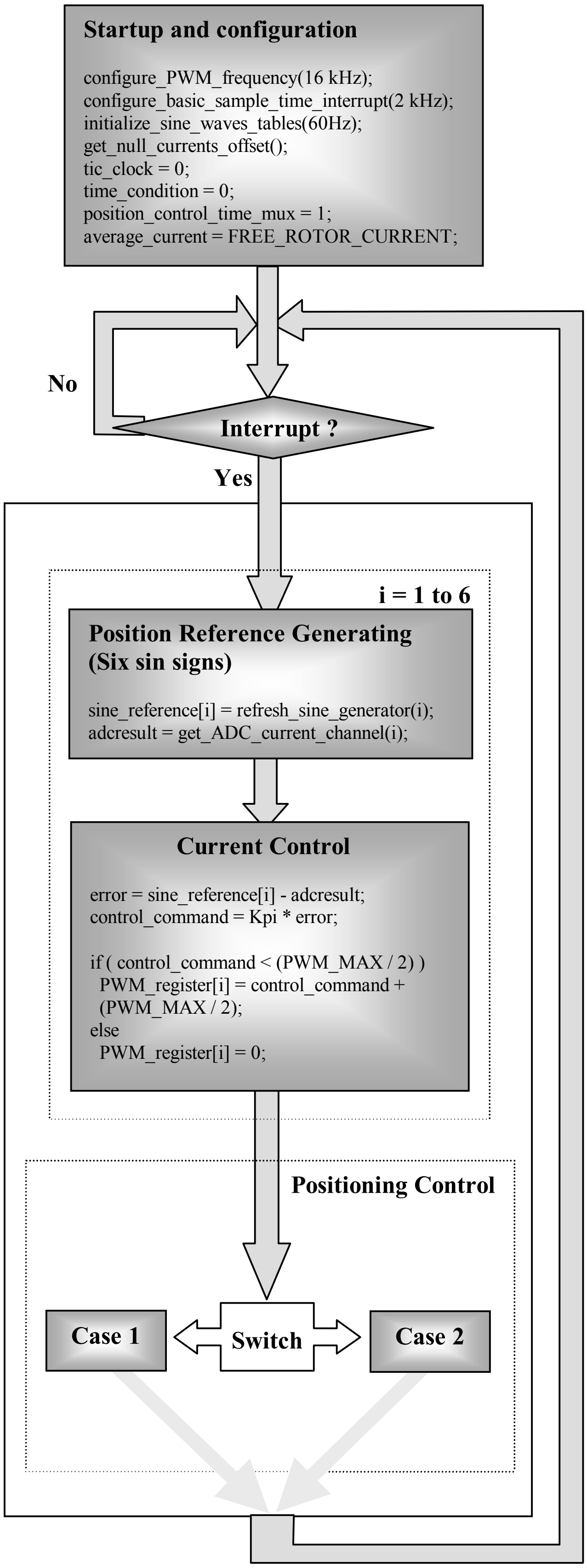

Figure 3a: Control Program Fluxogram

Case 1

```
do_nothing();
position_control_time_mux = 2;
break;
```

Case 2

```
adcresult = get_ADC_X_position_channel();
control_command =
PID_control_X_axis(adcresult, X_reference);
phase_A_1_sine_amplitude = average_current +
control_command;
phase_A_2_sine_amplitude = average_current -
control_command;

adcresult = get_ADC_Y_position_channel();
control_command =
PID_control_Y_axis(adcresult, Y_reference);
phase_B_1_sine_amplitude = average_current +
control_command;
phase_B_2_sine_amplitude = average_current -
control_command;
phase_C_1_sine_amplitude =
phase_B_1_sine_amplitude;
phase_C_2_sine_amplitude =
phase_B_2_sine_amplitude ;
position_control_time_mux = 1;
break;
```

Figure 3b: Positioning control updating.

After the six PWM registers has been updated, the algorithm uses the "mux" variable to alternate between cases 1 and 2, so that the PID position controllers actuate only at half the frequency of the currents controllers. That is because of the slower dynamics of positioning control.

It could be possible to optimize code using Assembly, but it would demand much more time of development. Since it was verified that the whole control loop executed in an adequate sampling time using C, this could be mantained. With this aproach, it became much easier to make modifications on the structure of the algorith and get the best configuration of some alternatives.

For the algorithm development, testing and debugging purposes, the Texas Instruments®' Code Composer 4.12 environment is being used [6]. It has code generation tools (compiler, assembler and linker) that accept American National Standards Institute (ANSI) standard C source code and produce assembly language source code to the TMS320LF2407A. Besides, it provides real time analysis, a debugger and simulators that have been very useful since they allow good control and visibility of the code execution.

The algorithm implemented basically consists of: initial system configurations, as well as configurations of the DSP modules and after that, the program keeps looping infinitely, executing an interrupt service routine, called every 500 microsseconds. This routine is responsible for the current and position controllers and, in the future, the rotational speed control will be included.

IV. EXPERIMENTAL RESULTS

The first results obtained are the sinusoidal current waveforms imposed at each coil of the motor's stator. This is the first step towards the accomplishment of the position control: each one of the six branches of the inverter must be controlled independently. The Fig. 4 shows two of the six currents with 120 degrees of phase difference could be observed indirectly through the response of isolated current transducers.

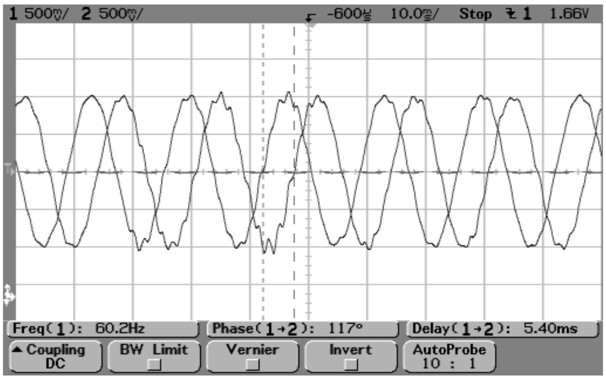

Figure 4:. Controlled stator currents of two phases (0.5 A/Div)

At this initial test, the rotor did not have any winding, making the machine to behave very close to the ideal model of an inductor (magnetization branch) in parallel with a resistor (iron loss branch), without any influence of rotor movement. This simple model allows a proportional controller to be efficiently applicated, optimizing, thus, the computation time required at the deepest level of the control system (the currents control).

In the Fig. 5 is shown the response of the sensor position with control bearing. The external circle shows the maximum rotor orbit. The central point is the real time rotor position controlled by PID.

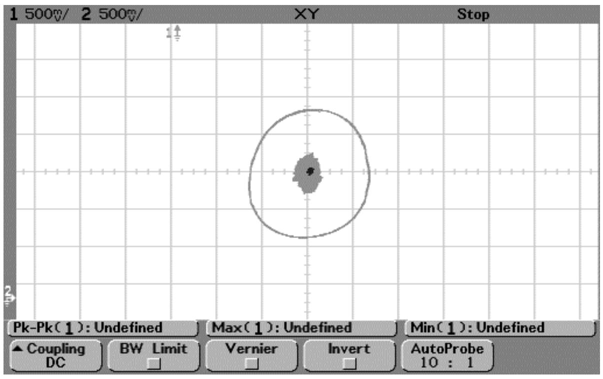

Figure 5:. Response of position sensor (0,5 mm/div)

It can be observed, that the control maintains the axis of the very close rotor to the reference position.

The Fig. 6a shows the position control acting in the **X** direction for the first system (with PC) and the Fig. 6b for the second system (With DSP).

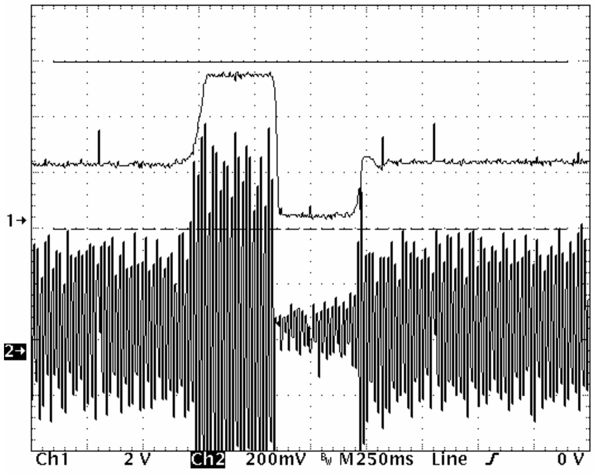

Fig.6a: **X** axe Current position control performance - PC.
Axe y: 2 A/div; Axe x : 100 mS/div.

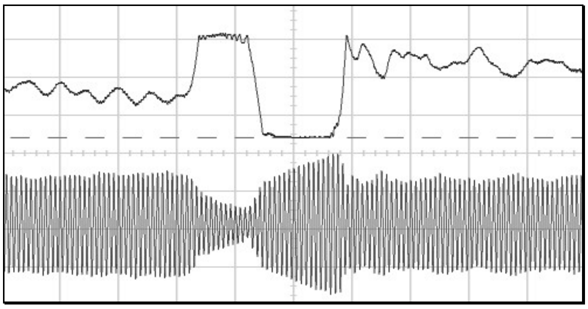

Fig.6b: **X** axe Current position control performance - DSP.
Axe y: 2 A/div; Axe x : 100 mS/div

The higher frequency sign is the opposite winding current sign in this axe. When the sensor sign is decreased this means that the rotor is getting closer to sensor and the winding is far. The other sign in the Figs. 6a and 6b is from the position sensor. When the rotor approaches of the winding the control decrease the current to reduce its force. Exactly the contrary occurs in the opposite winding that must amplify the attraction force increasing its current.

The fig. 7 shows the stator current versus radial force. The range of the weights added on the rotor axis is from 0 kg to 1.28 kg.

It can be observed the necessary current for the rotor repositioning is approximately linear in the force stable range.

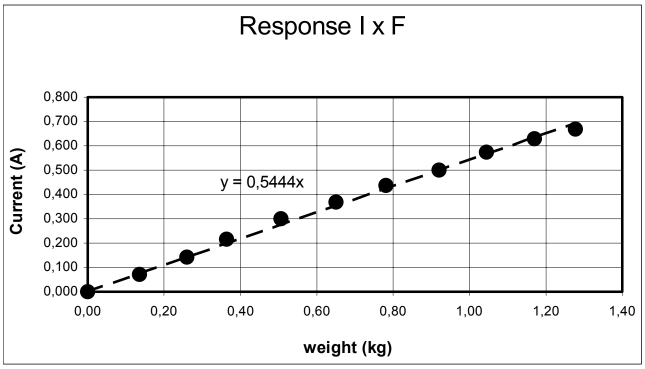

Figure 7:. Response of Current versus radial Force

V. CONCLUSION AND PERSPECTIVES

In agreement with the obtained results, the efficiency of the used DSP can be proven, due to fast response of control signals observed, low distortions in the stator currents and good stifness with the position control. The DSP allows the implementation of a lower cost and compact system, because it groups all inputs and outputs in only one device.

The obtained results showed that the process runs fast. The positioning controller strategy has been optimized and good chances are that it will became more robust.

Another objective of this work, in the near future, is the implementation of fuzzy and fuzzy-neural controllers to establish a direct comparison with the PID controller for rotational speed and radial position.

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