

Instrumentation and Control Strategy of a Linear Switched Reluctance Actuator

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Abstract

This paper concerns the instrumentation and adoption of a control strategy, applied to an already built Linear Switched Reluctance Actuator (LSRA). First approach has consisted in making dedicated study of the LSRA, having in special attention its electromagnetic aspects, being in spite of this essential some published works [1-5].

The knowledge of actuator's characteristics makes possible the adoption of proper control strategy, on basis of some obtained signals, as those corresponding to the position, velocity, current and voltage.

Data acquisition was made by microcontroller MSP430H449, after substituted by microcontroller TMS320F2812, due to the inability of the first to provide simultaneously data acquisition with more complex actuator's control.

Keywords: Linear Switched Reluctance (LSRA), Instrumentation, Data Acquisition, Control Strategy.

1. Introduction

This work is in within the fields of control, instrumentation and data acquisition of linear electrical machines. The machine under analysis and control process is one of switched reluctance and intends to be applied in machine tools.

The actuator, object of this instrumentation and control work, is a quite complex machine, in terms of electromagnetic analysis, with flux distributions variables, both with physical configuration and with position, along the movement. Thus, the control of this kind of machine it is, in the author's point of view, a very interesting challenge to perform.

2. The LSRA

Figure 1 shows the actuator under study, mounted on a test branch, being the primary the mover and the secondary the stator. A laminated core, supporting six coils, constitutes the machine primary, being the

secondary one iron bar, in which had been welded small iron blocks, equally spaced on proper places, defined by a design methodology already defined in [1,3,6].



Fig. 1. LSRA prototype

The actuator's movement results from the feeding of pairs of coils (phases) in positions corresponding to polar regions of partial overlapping with secondary teeth, being the other pair in an aligned position, where the inductance is maximum, and another pair in an unaligned position, where the inductance is minimum.

For this actuators, the alignment position, even for not considerable current values, it is very propitious for the occurrence of saturation of its magnetic circuit; this fact is not occurring in positions near the unalignment, because the reluctance of the magnetic circuit is high, and the leakage flux is low.

If the desired movement is that from right to left, the sequence of phases feeding is pairs 2 2', 1 1' and 3 3'; otherwise, the sequence is pairs 3 3', 2 2' and 1 1'. The control of the phase voltage is made trough the firing of electronics switches, in well defined instants.

For an effective and suitable machine control it is necessary to know the magnetic characteristics and the performance characteristics, in terms of developed force and possible velocity for specific feeding conditions, current profiles and firing positions. The previously developed work [1,4,6] made possible the knowledge of such characteristics, as is, for example the traction force F versus position x , for different current levels I , as shown in Fig. 2.

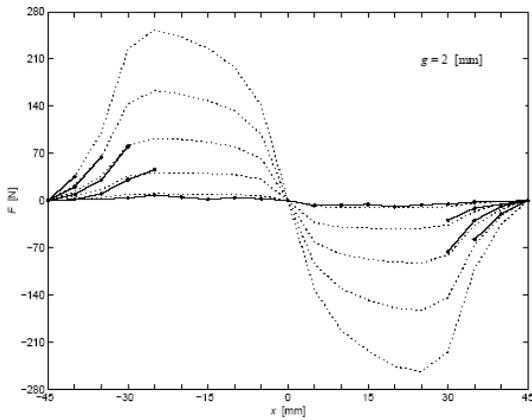


Fig. 2. Characteristics of traction force versus position, for different current levels for a 2 mm airgap (dotted line - theoretical values; solid line – practical values)

Based on obtained characteristics is still possible to define limits of excitation; that means, the maximum possible value of current, and the maximum value of traction forces, for all relative secondary positions.

3. Instrumentation

The instrumentation of the LSRA was made, with the objective to acquire its position, speed, current and voltage.

A. Position acquisition

For position acquisition, an optic sensor OPB704 joint together with actuator's secondary part was adopted, as shown in Fig. 3.

The optic sensor is an incremental encoder presenting one of two states, that can be obtained, for example, considering a two colours band (black and white), or from different distances to metal pieces (machine secondary, with saliencies). The main parts of this sensor are an emission diode and a photoreceptor. The photoreceptor absorbs different light reflex, depending on the colour of the band that is on the influence of the emission diode, being this way generated an impulse train, corresponding to the distance between black and white colours. As small is the space between bands, higher is the sensor resolution. A disadvantage of this method is that is not possible to determine the direction of the movement, and that's why it was been adopted a quadrature encoder, where two different black and white bands are positioned with 90° displacement, being possible to known the movement direction, with two optic sensors. In the presented work, a spaced band of paper of 2 [mm], with colours black and white, positioned in the test branch (Fig. 4), allows the generation of wanted pulses, when the sensor is passing trough the band. On the same figure, a larger paper band can be seen, giving a lower resolution solution, with lower 5 [mm], that was used as initial developing point.

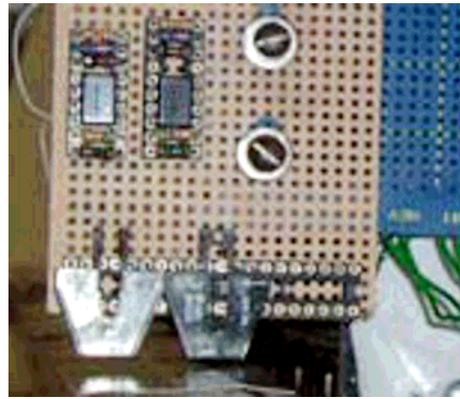


Fig. 3. Optic sensors

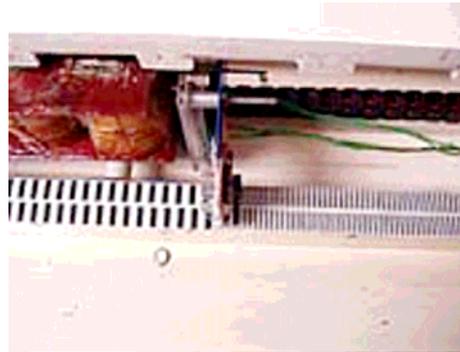


Fig. 4. Black and white paper band

The designed circuit for the position signal acquisition is shown in Fig.5, where a rectangular wave, with levels 0 and 3 V is obtained, with period corresponding to a 4 mm distance. The position is determinate trough proper software, and the phases feeding sequence imposes the machine movement direction.

The resistance of 100 [Ω] is used for the limitation of the diode current, and the one of 55,5 [KΩ] is used for the transistor polarization and current limitation.

Concerning the comparing circuit, a parasite voltage tends to appear when the sensor signal is too low, and is necessary to compensate a voltage with about 15 V, as follows:

$$V_{comp} = \frac{R_4}{R_4 + R_5} \cdot V$$

$$0,15 = \frac{R_4}{R_4 + R_5} \cdot 3 \quad (1)$$

$$\begin{cases} R_4 = 10 \text{ K}\Omega \\ R_5 = 190 \text{ K}\Omega \end{cases}$$

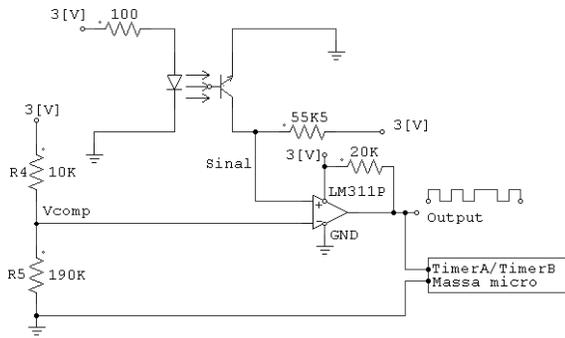


Fig.5. Pulse generation circuit for position acquisition

B. Velocity acquisition

For the acquisition of the signal corresponding to velocity, a frequency-voltage converter (LM2917) was used, as shown in Fig. 6.

The frequency of pulses, supplied by the previously described position sensing circuit, is converted into a continuous signal of voltage, proportional to actuator's velocity, with respective electronic circuit shown in Fig. 7.



Fig. 6. Optical sensors and frequency-voltage converter

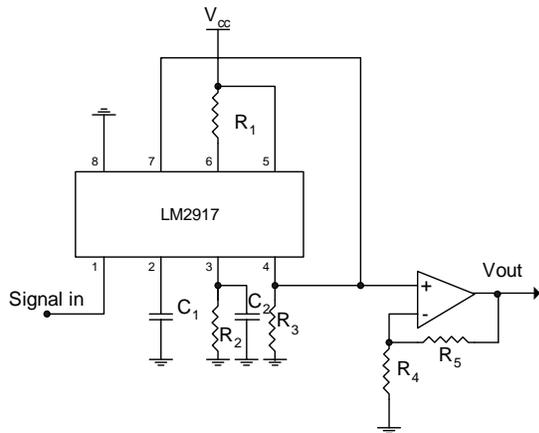


Fig. 7. Electronic circuit for velocity acquisition

The used components and connections between them are following the imposed by converter datasheet, with an additional amplification circuit, in order to obtain a

widening in voltage range. The obtained frequency/voltage characteristic is presented in Fig. 8.

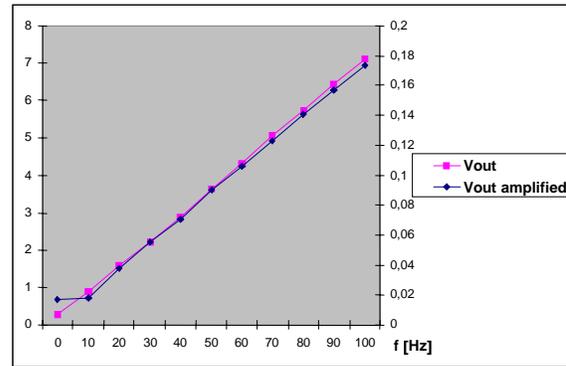


Fig. 8. Electronic circuit for velocity acquisition

C. Current and voltage acquisition

For current acquisition, three Hall effect sensors, one for each phase of the machine, were adopted (Fig. 10). The voltage was then obtained through a circuit based on a voltage division circuit, with proper protection system, connected to the mentioned three machine phases.

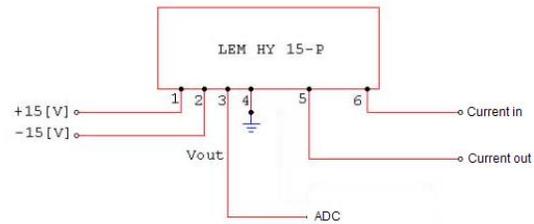


Fig. 10. Current acquisition circuit

Figures 11 and 12 shown the obtained characteristics, of current and voltage, respectively, from the described acquisition circuits.

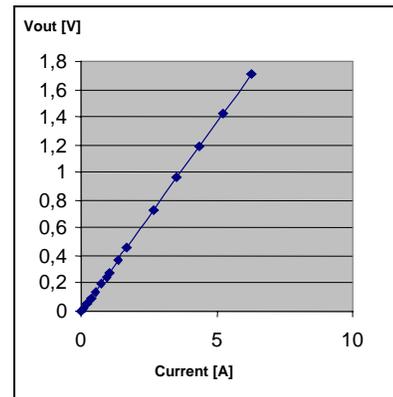


Fig. 11. Current characteristic obtained from the acquisition system

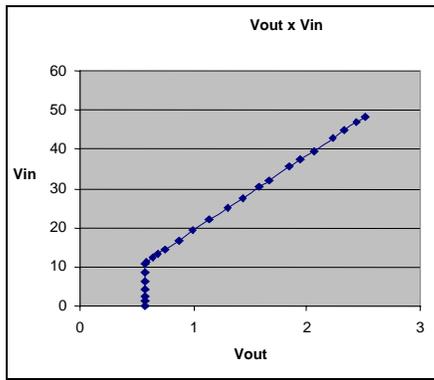


Fig. 12. Voltage characteristic obtained from the acquisition system

4. Data Acquisition and Control Strategy

The data acquisition was made appealing to microcontroller MSP430H449 [2]. This device makes real time system data acquisition (position, direction, current, velocity) and based on it, determines the exact moment to turn on or turn off power to each actuator phase coil. That is exactly the philosophy behind the adopted control strategy, being mandatory the current that has to be injected in each three machine phases.

The microcontroller software, together with feed provided through a sequential connection of phase coils to a forced switching circuit DC/DC (Fig. 13), imposes the average current value, and was designed using a simulation software.

The switching circuit DC/DC operation can be shortly described: for an initial circuit state, the capacitor is charged and a residual current is flowing in load (machine coil), through the free wheeling diode, until be extinguished. The firing in the tiristor 1 makes possible two different circulating meshes: one through the tiristor and load and another through the capacitor, inverting his voltage and charge polarities, existing until maximum value; after this process, the only existing circulation is through load and the current is maximised. After a firing in tiristor 2, the voltage of capacitor is once more inverted, being now extinguished the current through load and tiristor 1, and the current in load is provided by capacitor and tiristor 2 branch, until complete capacitor charge. The initial condition is then achieved once more, and conducting process can be repeated.

The aspect of current profile can be seen in Fig. 14, being t_0 the instant of tiristor 1 firing and t_1 the instant where the current reach the maximum value, or the value defined by control strategy; in t_1 the tiristor 2 is fired and the tiristor 1 is turned off; between t_1 and t_2 the free wheeling diode is conducting, and load current becomes lower; t_2 correspond to the next firing process in tiristor 1.

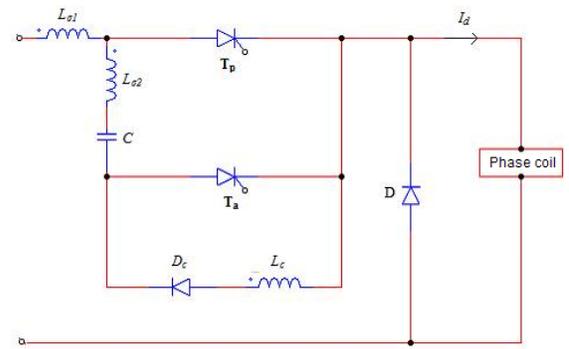


Fig. 13. Power driver phase feeder

Instants for connection and excitation duration are as well defined by the software control strategy, and the wanted machine velocity, and or the required device traction force determine the necessary current value to be supplied.

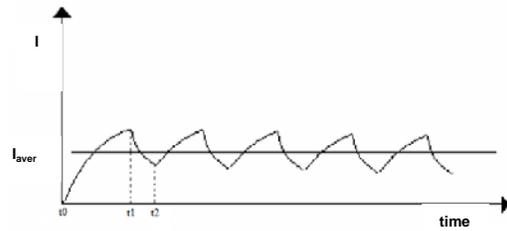


Fig. 14. Coil current profile

Concerning the firing circuit, the adopted scheme was the shown in Fig. 15. A phototriac was chosen in order to be possible an optic isolation between the power circuit and the microcontroller circuit.

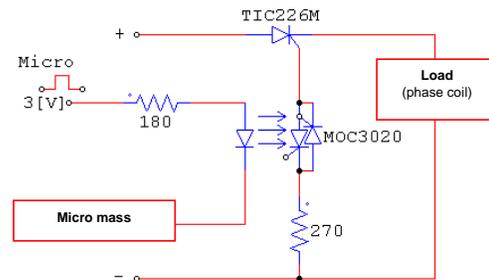


Fig. 15. Tiristor firing circuit

The control circuits were design such a way that they were totally independent, being each circuit controlling each current flowing in phase coils.

5. Data Acquisition and Control Software

The data acquisition software was developed using C language, together with an Integrated Development Environment for the MSP430H449 microcontroller, and the flowchart of that software program is shown in Fig. 16.

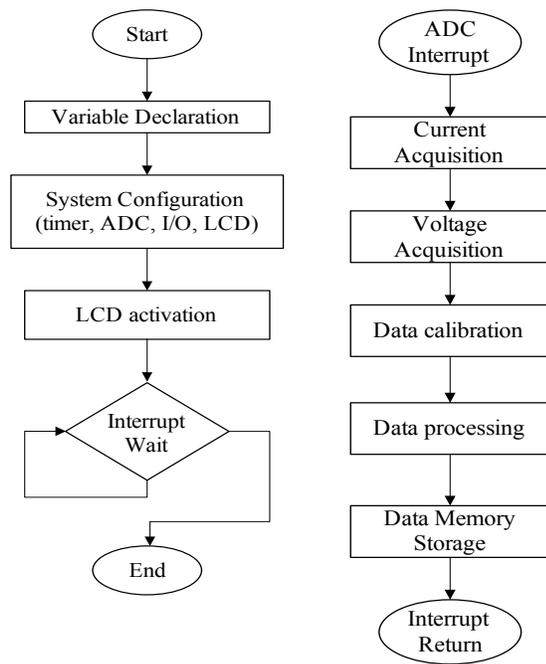


Fig. 16. Main software and ADC interrupt flowcharts

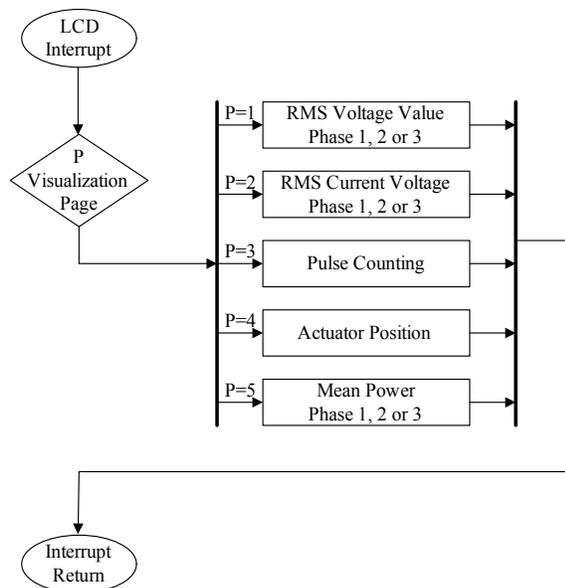


Fig. 17. LCD data refreshment interrupt flowchart

The software first concern it was the adopted microcontroller identification, and the establishment of all used global variables; after that the hardware had to be configured, as are the microcontroller ports, the ADC, Timers, and others. Finally, the LCD was worked, in order to obtain all visualizations needed, as are the knowledge of current, voltage, pulses, position, velocity, etc.

A clock routine was made, with refresh cycle of 128 Hz, being observed two course-end sensors, and a middle frequency is stated for the construction of a 64 elements vector, that contains the observed phase currents and

voltages, then supplied to the ADC. Also, the calculation of active power is performed, and the visualization of pulses and machine position values is possible.

The ADC cycle contains the signals acquisition algorithm, as well as the calibration software. The main program has the ability of coordinate all subroutines and tasks, in order to acquire available signals and decide proper actuation of semiconductors connected to coils, allowing the demanding position, velocity and traction force.

6. Conclusion

The dedicated study of the switched reluctance actuator, with complete characterisation, in terms of its principle of functioning and its main characteristics, allows delineating strategies to make its control and instrumentation, having in account the physical and economic aspects of the sensors.

This actuator has as advantage of enormous force of traction. The adopted methodology permits the control of the SLRA, being possible, for a specific actuator application, to state proper excitation time and machine position, taking into account the required velocity and traction force.

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