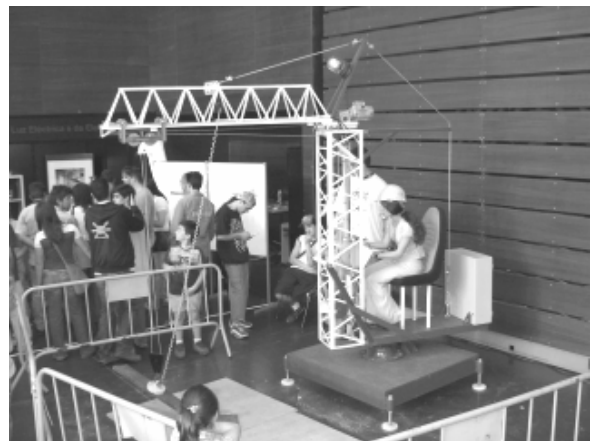


electromagnet, which cannot be switched off while being on a high position, not even if the emergency button is pressed.

**Keywords.** Electromagnet, Switchboard, Contactor, Inverter, 8051 Microcontroller.

## 1. Introduction

A science fair slewing crane described in a separate paper (Fig. 1) has an electromagnet and is controlled by a switchboard. Both devices are presented in this paper.



**Figure 1. Slewing crane at *Robótica 2006* festival**

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## Electromagnet and Switchboard for Slewing Crane

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**Abstract.** This paper presents an electromagnet and a switchboard used on a science fair slewing crane described in a separate paper. The electromagnet can lift 50kg loads. The switchboard includes a transformer that powers the electromagnet. It also contains relays, contactors and inverters that allow the operation of the crane three-phase motors using a single-phase power supply. Crane slewing is limited to an 180° angle, for safety reasons. Pressing an emergency button switches off all command circuits. An 8051 microcontroller-based system determines the vertical position of the

The switchboard (Fig.2) receives command signals from a control panel (Fig. 3) and two limit switches. According to these signals, it switches the electromagnet (Fig. 4) on or off and controls three three-phase motors. One of the motors is responsible for slewing the crane right or left. The other two enable the electromagnet to move up, down, forward or backward.

## 2. Materials used

The following materials were used to build the switchboard and the control panel:

- 2 inverters;
- 1 power source;
- 1 remote control;
- 10 relays;
- 2 contactors;
- 1 transformer;
- 2 circuit breakers;
- 33 connectors;

- 1 roll of 0.75mm<sup>2</sup> cable;
- 1 roll of 2.5mm<sup>2</sup> cable;
- 1 switchboard case;
- 1 emergency switch;
- 1 two-position joystick;
- 1 four-position joystick;
- 1 pushbutton;
- 4 limit switches.

The following materials were used to build the electromagnet:

- Varnished 0,25mm<sup>2</sup> copper wire.
- Cylindrical piece of iron with a diameter of 15cm and an height of 4cm.

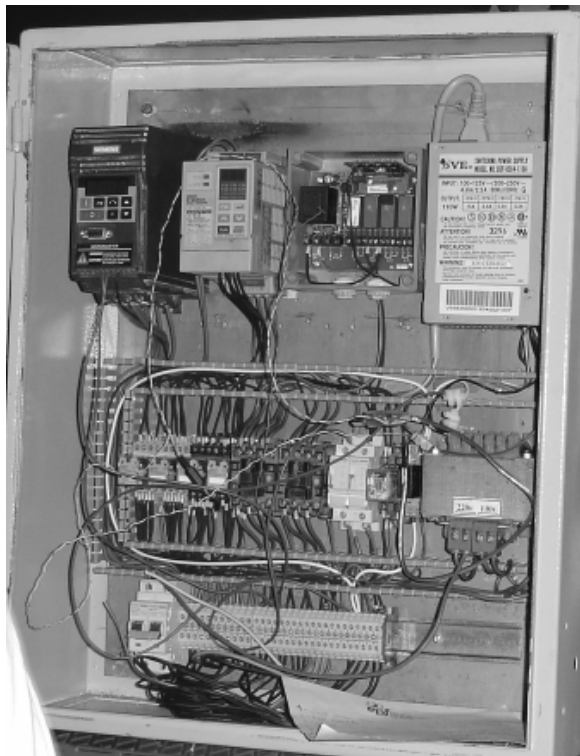


Figure 2. The switchboard

### 3. Switchboard operation

The switchboard contains several command circuits [1] that are active as long as Relay 6 (Fig. 5) is active. The control panel has an emergency button s1 (Fig. 5). Pressing this button switches off Relay 6. It is also possible to switch on or off Relay 6 using a remote control (Fig. 5).

In order to keep 230V mains voltage as the only power source of the crane, inverters were

used to drive the three-phase motors. Fig. 6 depicts the command circuit of inverter 1, which drives the motor that moves the electromagnet up or down. The sense of motion is done according to the position of a two-position joystick s2, placed in the control panel. Pressing the emergency button stops the electromagnet movement.



Figure 3. A young visitor to *Robótica 2006* festival operating the control panel (the switchboard is behind the operator's seat)

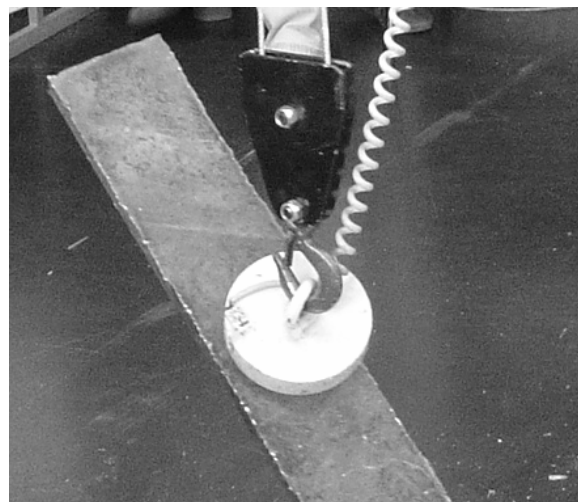
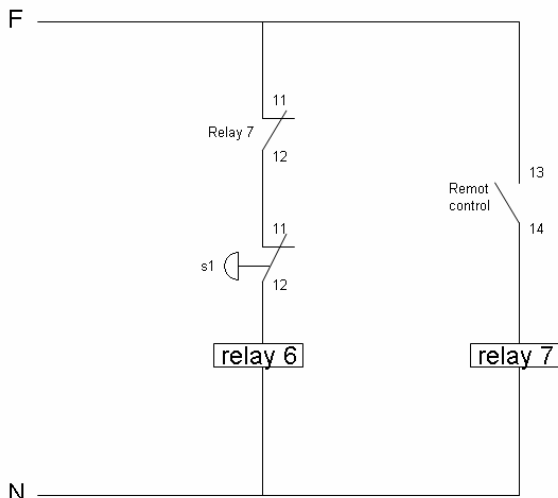


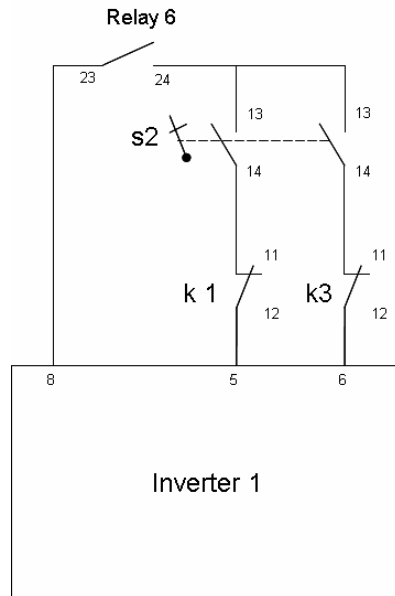
Figure 4. The electromagnet

Fig. 7 shows the command circuit of the relays used to command the inverters and to switch on and off the electromagnet. Two limit switches were used to ensure that the electromagnet stops when its forward or backward movements limits are reached. Two more limit switches were used to ensure that the crane only slews within an 180° angle.

It is not possible to use limit switches to determine the vertical position of the electromagnet. So, a system based on an 8051 microcontroller (Fig.8) was developed [2, 3, 4, 5, 6]. An inductive sensor (Fig. 9) is placed near the reel of the cable that holds the electromagnet. For each reel turn, the sensor sends one signal to the microcontroller. Electromagnet height is determined by counting these turns.

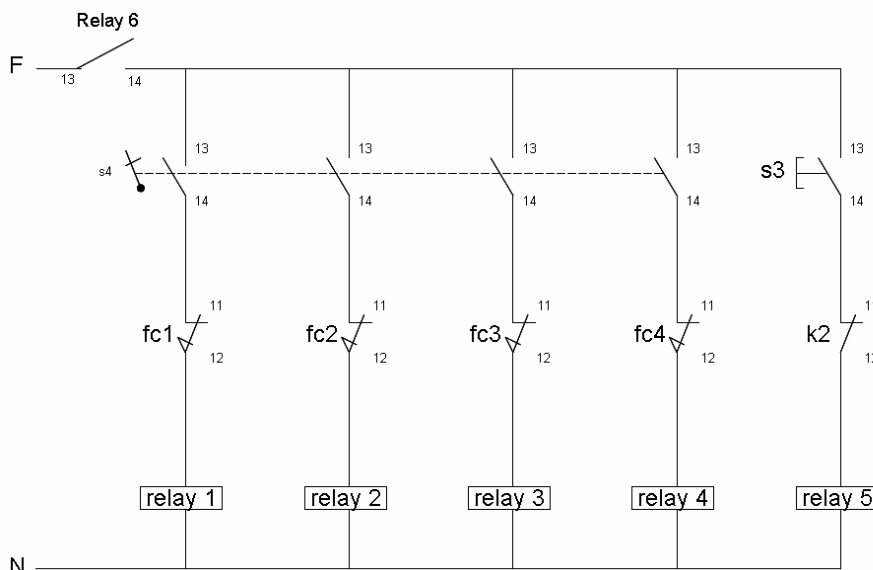


**Figure 5. Emergency button and remote control function**



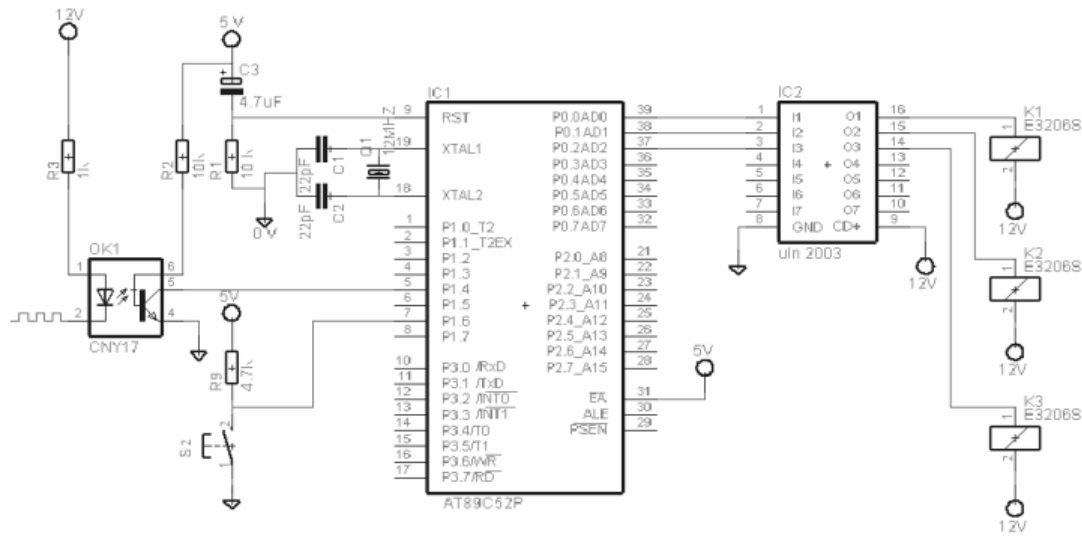
**Figure 6. Command circuit of inverter 1**

The electromagnet can be raised to a height of up to 2m from the ground. For safety reasons, an operator is not be able to switch off the electromagnet if it is above 0,50m level from the ground, not even if the emergency button is pressed.

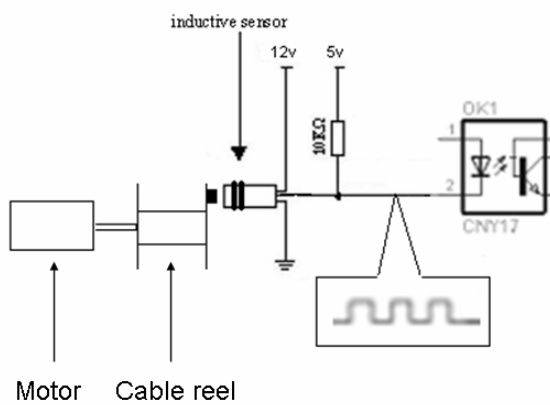


- s3 – pushbutton that switches the electromagnet on or off.
- s4 – four-position joystick, which allows the operator to slew the crane right or left and move the electromagnet forward or backward.
- fc1 – left slewing limit switch.
- fc2 – right slewing limit switch.
- fc3 – forward movement limit switch.
- fc4 – backward movement limit switch.

**Figure 7. Command circuit of the relays used to command the inverters and to switch on and off the electromagnet**



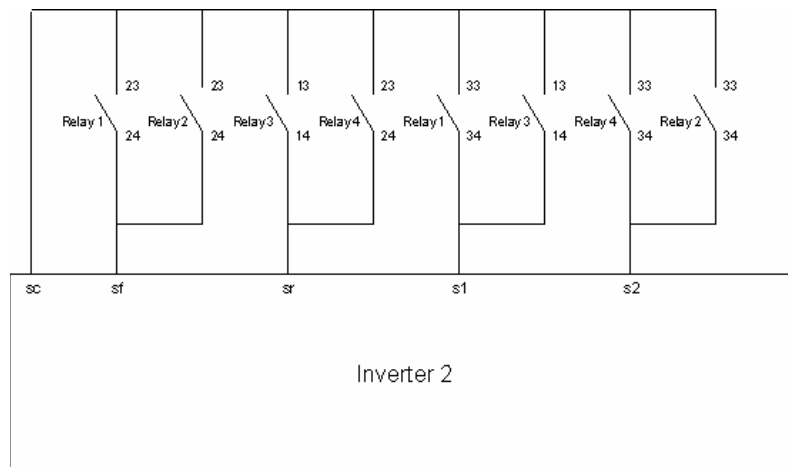
**Figure 8. 8051 microcontroller circuit**



**Figure 9. Connection of the inductive sensor to the microcontroller**

Auxiliary relays were used to control inverter 2 (Fig. 10). This inverter drives both the motor that slews the crane and the motor that moves the electromagnet forward and backward. The two movements cannot occur at the same time. So, only one inverter was used, instead of two.

Two contactors (Fig. 11) were used to switch the motors on and off. The command of the contactors is done by a four-position joystick, which allows the operator to slew the crane right or left and move the electromagnet forward or backward. Since an operator is not able to select two different positions of the joystick at the same time, it is not possible to activate both motors at the same time.



**Figure 10. Command circuit of inverter 2**

Each signal received from the four-position joystick activates a specific relay, which switches on one of the contactors. At the same

time, the relay tells inverter 2 which motor should start and which is the sense of rotation of the rotor. Fig. 12 shows the power circuit, which

includes a transformer that powers the electromagnet.

Whenever the emergency button is pressed, all command circuits stop functioning. However, if the electromagnet is switched on at that time, it will not be turned off.

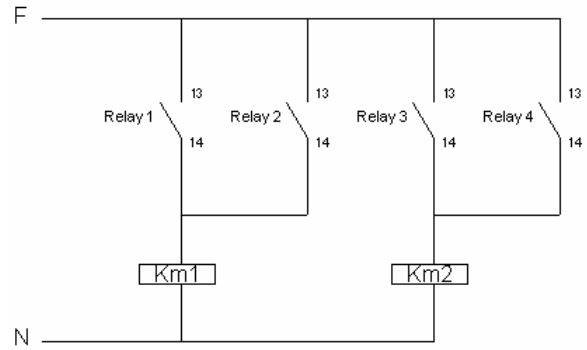


Figure 11. Command circuit of the contactors

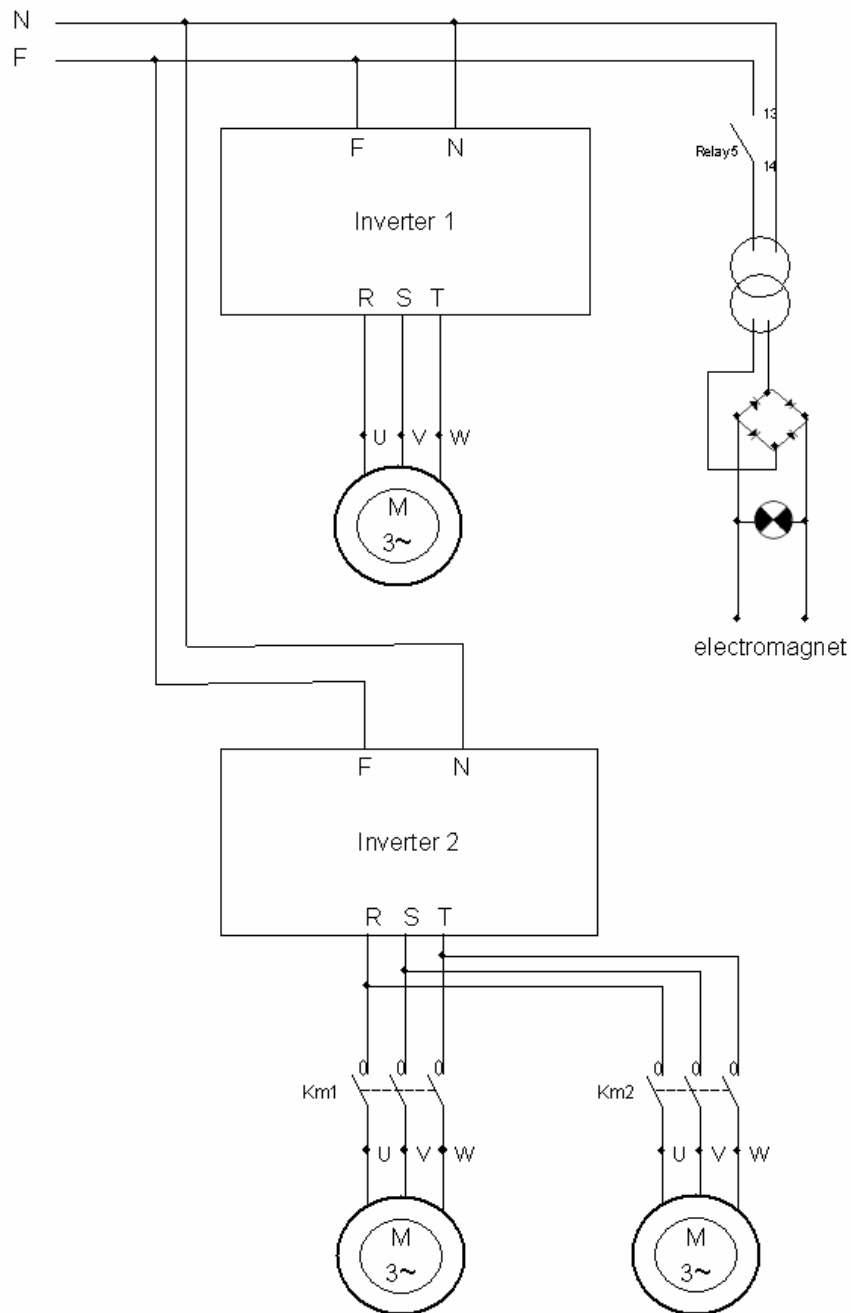


Figure 12. Power circuit

#### 4. Source code of the program installed in the 8051 microcontroller

This is the source code of the program used by the 8051 microcontroller to determine the vertical position of the electromagnet:

```
#include <REG51.H>
#include <portas.h>

int conta=0;

void actualiza(void)
{
    int i;
    if(P16==1)
    {
        for(i=0;i<=15000;i++);// To eliminate the bounce effect
        if(P16==1)
            conta=conta+1;// If gate P1.6=1 increases the conta
    }
    if(P16==0)
    {
        for(i=0;i<=15000;i++);// To eliminate the bounce effect
        if(P16==0)
            conta=conta-1;// If gate P16=0 decreases the conta
    }
}

// The function verifies the counter state and acts according the
// conditions...//
void verifica(void)
{
    if(conta<=14&&conta>=10||conta==0)
    {
        if(conta==0)// If the counter goes " 0 " it turns off the
            ascent command
            P00=1;
        if(conta>=10)// When the counter is in the middle sends a
            sign
            P01=1;
        if(conta==14)// If the counter goes " 0 " it turns off the
            descent command
            P02=1;
    }
    else
    {
        P00=0; P01=0; P02=0;
    }
}
//.....//
int main()
{
    int i;
    while(1)
    {
        if(P14==1)
        {
            for(i=0;i<=15000;i++);//To eliminate the bounce
            effect
            if(P14==1)
            {
                actualiza();
                verifica();
            }
            }while(P14==1){}
    }
    return 0;
}
```

Remarks:

- Whenever gate P14 (Fig. 8) has a logical level 1 the program executes the *actualiza* instruction, which updates the *conta* variable. This updating depends on the logical level of gate P16 (Fig. 8).
- The *verifica* instruction has the purpose of verifying the state of the *conta* variable.
  - If *conta*=0 then gate P00=1 (Fig. 8). This disables the electrical circuit through the relay K1 (Fig. 8), which turns off the ascent circuit.
  - If the value of *conta* is between 10 and 14, gate P01 (Fig. 8) has a logical level 1. That will switch on relay K2 (Fig. 8).
  - If the value of *conta* is 14, that means the electromagnet is at the ground level. Gate P02 (Fig. 8) stays at logical level 1. This activates relay K3 (Fig. 8), which shuts down the electrical circuit, allowing the electromagnet to go down.

#### 6. Electromagnet construction and operation

The core of the electromagnet (Fig. 13) was made with a 15cm diameter cylindrical iron piece with a cavity.

A coil with 3500 turns of 0,25mm<sup>2</sup> varnished copper wire was placed inside this cavity. Fig. 13 shows an inside view of the device.

To activate the electromagnet, an 110V DC voltage is applied to the coil terminals. Then, a continuous current flows in the coil, producing a constant magnetic field [7, 8]. The electromagnet can lift 50kg loads.

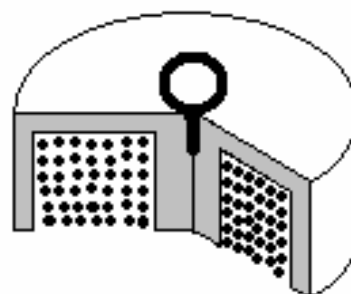


Figure 13. Electromagnet

## 7. Conclusions

An electromagnet and a switchboard used on a slewing crane built for science fair events have been presented.

The constructed electromagnet is capable of lifting ferromagnetic loads of up to 50kg, which can be raised to a height of up to 2m from the ground.

The switchboard contains relays, contactors and inverters that allow the operation of the crane three-phase motors using a single-phase power supply.

The switchboard also includes a transformer that powers the electromagnet.

On a control panel, a two-position joystick allows the operator to move the electromagnet up or down. A four-position joystick allows the operator to slew the crane right or left and move the electromagnet forward or backward. Pressing an emergency button switches off all command circuits. It is also possible to switch on or off these circuits using a remote control

An 8051 microcontroller-based system was developed to determine the vertical position of the electromagnet, which cannot be switched off while being on a high position, not even if the emergency button is pressed.

## 8. Acknowledgements

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