

## Foldable Slewing Crane

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### Introduction

A slewing crane equipped with an electromagnet is a very useful tool to move ferromagnetic pieces from a place to another. This paper describes such a crane, built for science fair events. Its first public appearance took place in the activity *Oficinas de Electricidade* (Electricity Workshops), integrating part of *Robótica 2006* festival<sup>15</sup> (Figure 1). Building this kind of equipment improves construction skills and promotes the study of Electromagnetism fundamentals, such as Biot-Savart's law [1, 2].

### Crane dimensions and operating details

The crane has a weight of 395 kg, a height of 3m and a length of 2,5m. The base is a 1,20m x 1,20m square. More detailed dimensions are shown in Figure 2.

Three three-phase induction motors, each one equipped with a reduction gear, produce the crane movements. A switchboard located at the rear of the crane (Figure 3) receives command signals from a control panel (Figure 4) and two limit switches. According to these signals, it switches the electromagnet (Figure 5) on or off and controls the motors. One of the motors enables the crane to slew right or left. The other two enable the electromagnet to move up, down, forward or backward (Figure 6). The control panel is located on the front part of the crane, where the operator – from its comfortable seat (Figure 7) – has a good view of the pieces to handle. For safety reasons, the crane is only allowed to slew within a 180° angle. This results in a working space whose top view has the shape depicted in Figure 8.

The electromagnet (Figure 9) and the structure of the crane are strong enough to elevate a weight of 80kg to a height of 2m from the ground.

Pressing an emergency button switches off all command circuits. However, the electromagnet cannot be switched off while being on a high position, not even if the emergency button is pressed.

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<sup>15</sup> *Robótica 2006 – Festival Nacional de Robótica* (National Robotics Festival), Guimarães, Portugal, April 28 – May 1, 2006.

The crane is foldable (Figure 10, 11 and 12), which is very convenient for transportation and storing.



Figure 1. Slewing crane at *Oficinas de Electricidade* (Electricity Workshops)

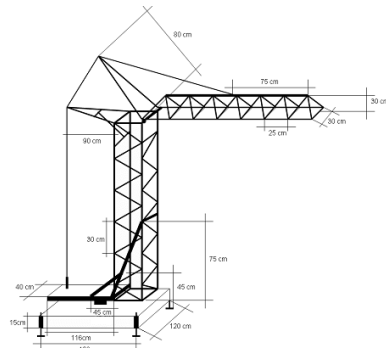


Figure 2. Dimensions of the crane

### Materials used to build the crane, the switchboard, the control panel and the electromagnet

The crane was built with:

- 10m of 30mm x 30mm angle iron;
- 24m of 16mm x 5mm iron bar;
- 6m of 25mm x 25mm iron tube;
- 2m of 30mm x 30mm iron tube;
- 5m of 150mm U-shape iron bar;
- 4m of 50mm U-shape iron bar;
- 2m of 65mm U-shape iron bar;
- a 1,7m x 1,2m iron sheet;
- 4 medium pulleys for steel cable;
- 8m of 4mm steel cable;
- 5m of 8mm steel cable;
- a truck hub;
- a seat;
- 4m of steel chain;
- 3 three-phase induction motors equipped with a reduction gear.

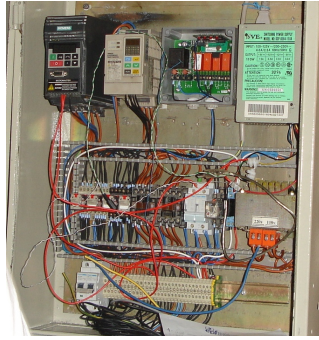


Figure 3. The switchboard



Figure 4. Operating the crane via the control panel  
(the switchboard is behind the operator's seat)

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  $0.75\text{mm}^2$  cable;
- 1 roll of  $2.5\text{mm}^2$  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  $0,25\text{mm}^2$  copper wire.
- Cylindrical piece of iron with a diameter of 15cm and a height of 4cm.

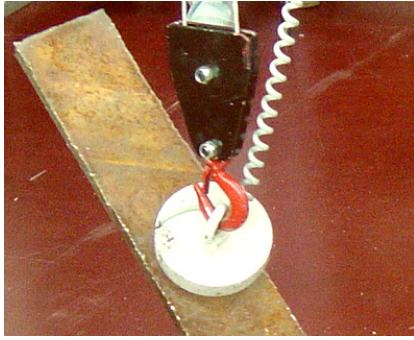


Figure 5. The electromagnet

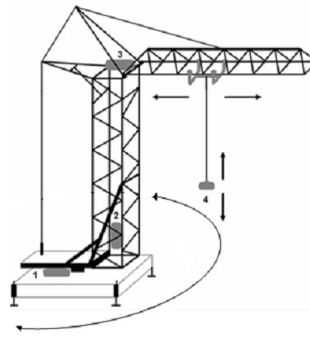


Figure 6. Crane and electromagnet movements



Figure 7. The crane has a comfortable seat

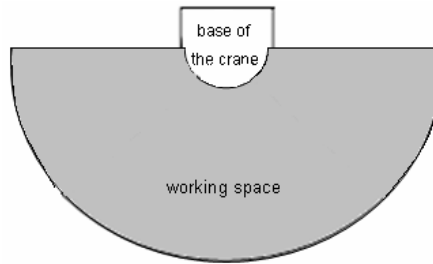


Figure 8. Top view of the working space of the crane

### Switchboard operation

The switchboard contains several command circuits [3] that are active as long as Relay 6 (Figure 13) is active. The control panel has an emergency button s1 (Figure 13). Pressing this button switches off Relay 6. It is also possible to switch on or off Relay 6 using a remote control (Figure 13).

In order to keep 230V mains voltage as the only power source of the crane, inverters were used to drive the three-phase motors. Figure 14 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 15 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 a 180° angle.



Figure 9. Electromagnet elevating an iron piece

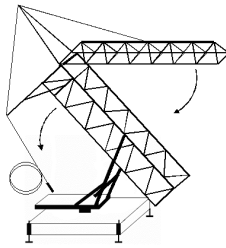


Figure 10. Folding the crane

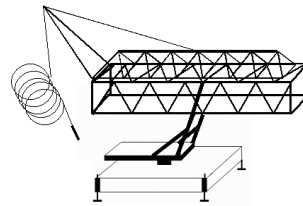


Figure 11. Folded crane



Figure 12. Folded crane being transported

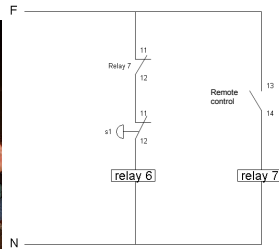


Figure 13. Emergency button and remote control function

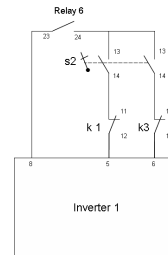


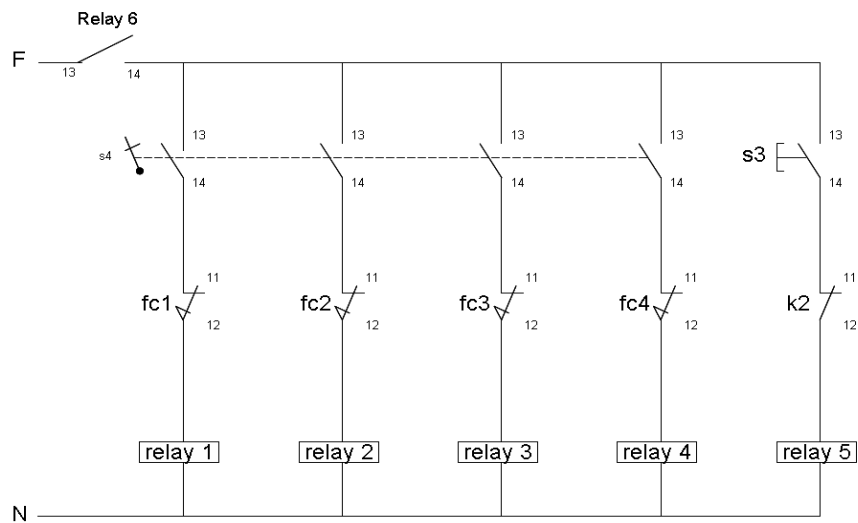
Figure 14. Command circuit of inverter 1

It is not possible to use limit switches to determine the vertical position of the electromagnet. So, a system based on an 8051 microcontroller (Figure16) was developed [4, 5, 6, 7, 8]. An inductive sensor (Figure 17) 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.

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.

Two contactors (Figure 18) 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. Auxiliary relays were used to control inverter 2 (Figure 19). 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.



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

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. Figure 20 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.

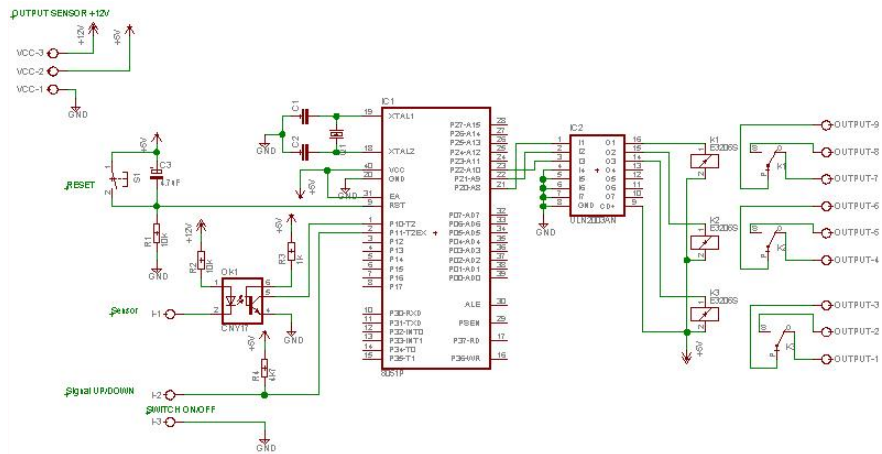


Figure 16. 8051 microcontroller circuit

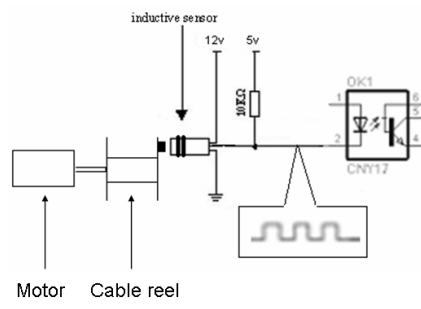


Figure 17. Connection of the inductive sensor to the microcontroller

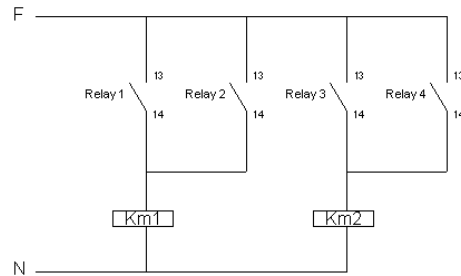


Figure 18. Command circuit of the contactors

### 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 count=0;
void update(void)
{
    int i;
```

```

if(P16==1)
{
    for(i=0;i<=15000;i++);// To eliminate the bounce effect
    if(P16==1)
        count=count+1;// If gate P1.6=1 increases the count
}
if(P16==0)
{
    for(i=0;i<=15000;i++);// To eliminate the bounce effect
    if(P16==0)
        count=count-1;// If gate P16=0 decreases the count
}
}
// The function verifies the counter state and acts according the //conditions....
void verification(void)
{
    if(count<=14&&count>=10||count==0)
    {
        if(count==0)// If the counter goes " 0 " it turns off the //ascent command
            P20=1;
        if(count>=10)// When the counter is in the middle sends //a sign
            P21=1;
        if(count==14)// If the counter goes " 0 " it turns off the //descent command
            P22=1;
    }
    else
    {
        P20=0; P21=0; P22=0;
    }
}
//.....//
int main()
{
    int i;
    while(1)
    {
        if(P14==1)
        {
            for(i=0;i<=15000;i++);//To eliminate the bounce //effect
            if(P14==1)
            {
                update();
                verification();
            }
        }
    }
    while(P14==1){}
}

```



```

    }
    return 0;
}
    
```

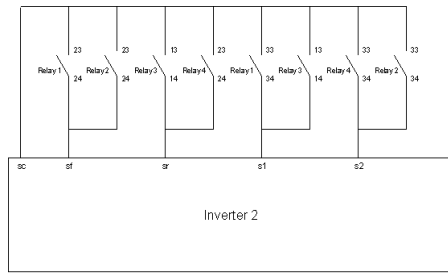


Figure 19. Command circuit of inverter 2

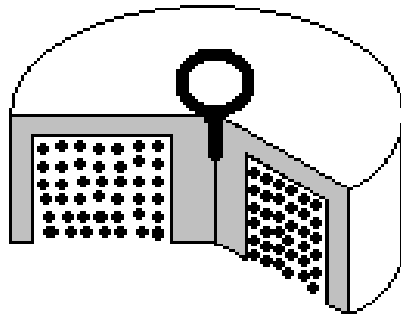


Figure 21. Electromagnet

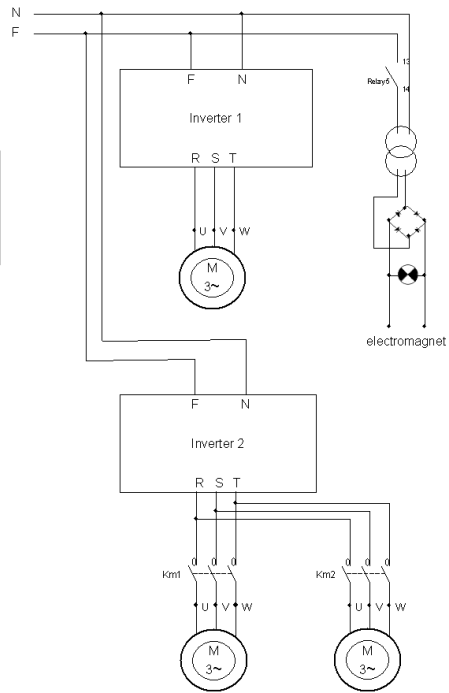


Figure 20. Power circuit

Remarks:

- Whenever gate P14 (Figure 16) has a logical level 1 the program executes the *update* instruction, which updates the *count* variable. This updating depends on the logical level of gate P16 (Figure 16).
- The *verification* instruction has the purpose of verifying the state of the *count* variable.
  - If *count*=0 then gate P20=1 (Figure 16). This disables the electrical circuit through the relay K1 (Figure 16), which turns off the ascent circuit.

—If the value of *count* is between 10 and 14, gate P21 (Figure 16) has a logical level 1. That will switch on relay K2 (Figure 16).

—If the value of *count* is 14, that means the electromagnet is at the ground level. Gate P22 (Figure 16) stays at logical level 1. This activates relay K3 (Figure 16), which shuts down the electrical circuit, allowing the electromagnet to go down.

### **Electromagnet construction and operation**

The core of the electromagnet 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. Figure 21 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 [1, 2]. The electromagnet can lift 80kg loads.

### **Conclusions**

A slewing crane equipped with an electromagnet has been presented. The device, built for science fair events, is capable of elevating ferromagnetic pieces of 80kg to a height of 2m from the ground.

Three three-phase induction motors produce the crane movements. The crane switchboard contains relays, contactors and inverters that allow the operation of these motors using a single-phase power supply. The switchboard also includes a transformer that powers the electromagnet.

On the crane 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. The operator can make the crane slew left or right within a 180° angle. 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.

This kind of project develops the construction skills of the builders and promotes the investigation of Electromagnetism fundamentals.

### **Acknowledgements**

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## References

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