Magnetically Impelled Kicker for Robotic Football in MSL RoboCup

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Abstract. This paper describes a kicking device used in RoboCup middle size league robotic football. In order to kick the ball in robotic football, several devices have been developed by many other teams. Some of these have been raising safety precautions due to its strength. In this work it was developed a magnetic impelled device, which is used as a kicking device. It uses an electric coil, in which a current passes through and attracts a cylindrical iron core. At the other end, a cylindrical shape nylon piece is attached to the metallic core and pushes the ball away. It is a strong kicking device which kicks both horizontally and upwards. It has being developed, used and improved in the last few years and its latest version is described in this paper, which includes its electronic circuit boards. This device can be used in other industrial or servicing applications.

1. INTRODUCTION

RoboCup is a scientific challenge created to foster research and development in fields like mobile and autonomous robotics, automation, electronics, computer vision and image processing, and other related areas. It consists of a football competition with several different leagues. For those unfamiliar with the RoboCup event, they can read the rules on [1].

On Middle Size league, most teams use a kicking device in order to score goals from a distant position from the goal. The use of a kicking device reduces the number of collisions and increases the chances of scoring goals. Many different techniques and devices have been created by as many teams for this purpose, and this paper describes how this specific kicker works and has been built.

This team already participated on previous RoboCup editions and has as main goal to develop a robotic football team capable of playing football as comparable as possible to humans. Previous participation's allowed this team to learn and improve the robots and these are becoming more and more reliable. The kicker has been under development and in the last event it had the facility of controlling the strength of the kick. It proved to be worth, and many goals were score for the pleasure of the public.

2. BACKGROUND

Many techniques are being used to score goals in robotic football. Some teams do not kick the ball at all. Instead they push the ball with the robot body towards the opponent goal and accelerate the robot movement. The advantages are simpler hardware, no need to interface with the robot system, and less waste of energy. But it also has disadvantages because the robots have to go into the goal to score. In those conditions the opponent keeper has more chances to defend the ball, and more chances to collide with each other which can be risky. A team which used this technique was Minho team [2] in 1999. In EuRoboCup'2000, in Amsterdam, the team introduced a new technique to kick the ball, and which consists of the first version of the device here described. It consisted on an electric coil which would magnetically attract a metallic core which would push the ball [3] and [4].

Some teams use compressed air to activate a kicking device. Pneumatic kicking device consists of a pneumatic cylinder, an electric valve, and a tank for compressed air. This technique has several advantages like being a standard system which can be bought off the shelf, it is relatively cheap, and is not faulty since it works with air. As main disadvantages, these systems are very noisy, need to be filled in with air from time to time, and reduced kick strength is obtained as the pressure in the vessel runs flat [5] and [6].

Other teams use a strong spring which is pulled by a motor, and when a kick is to be applied, the spring is release, pushing some kicking device. A spring can hold the largest amount of immediately and reproducibly releasable energy per unit of volume. This system has as main advantage the kick strength (it is one of the strongest if not the strongest) but as disadvantage the spring spindling in time which can be long. However, it is possible to kick right afterwards although this means they cannot kick with maximum power [7] and [8].

Another technique consists of a continuous spinning metallic sheet, which when touches the ball kicks it far away (this technique is most used in the small size league).

3. KICKING METHOD

The kicker consists basically of an electric coil with a movable core made up with two different materials: one length of iron and one length of nylon. Figure 1 shows the kicker apparatus. It can be seen that the iron part is mostly outside the electric coil and the nylon is mostly inside the coil void.

When electric current is applied to the electric coil, the core is pushed towards the nylon side so that the iron goes inside

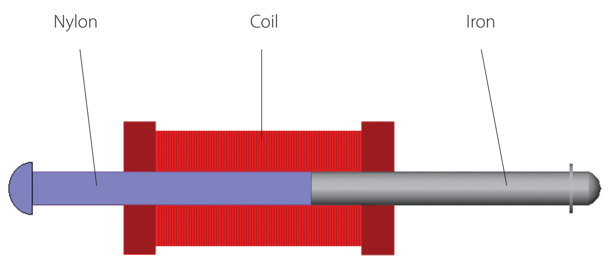

Figure 1. Kicker Apparatus.

the coil, and it is the nylon part that will pushes the ball, applying a certain speed to it. The force the core will have is proportional to the electric current that passes through the coil. That force is also proportional to the amount of iron used in the metallic core, and therefore pure iron is advised to be used. According to Newton's Law, the greater the force the greater the acceleration and therefore the greater the acceleration the greater the velocity with which the core will hit the ball. The kick must make contact with the ball when its velocity is maximum, in other words, just before the iron core arrives to the core center. At that point in time the kinetic energy transferred to the ball is given by:

$$Ec = \frac{1}{2} m \cdot v^2 \qquad [1]$$

where: m is the mass of the kick core
v is the velocity of the kick at the contact

3.1 Coil's Current Input

The coil's force will be as strong as the current in the coil.

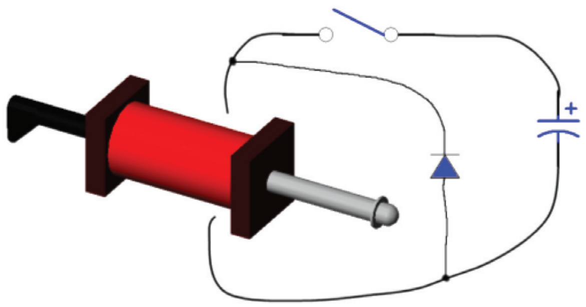

Figure 2. Kicker Discharge circuit.

The only way easiest and simplest way to inject a high current on the coil is with a high-voltage source. The device capable of that is a capacitor. The higher the capacitor's voltage, the higher the current peak at the coil during the discharge, and also the higher the accumulated energy. Figure 2 shows how the coil's high current is achieved. There is a switch to close the circuit's loop. The amount of time that the switch stays closed allows controlling the kick power.

The system uses twelve 10 mF capacitors serial connected.

$$\frac{1}{C} = \frac{1}{10 \times 10^{-3}} \times 12 \Leftrightarrow C = 833\, \mu F$$

After the capacitors being charged, the capacitor is equivalent to 833 µF and a 400 V. The energy stored and ready to be transformed into movement is given by:

$$E = \frac{1}{2} \cdot C \cdot V^2 = \frac{1}{2} \cdot 833 \times 10^{-6} \cdot 400^2 = 66.6\, J \qquad [2]$$

where: C is the capacitance
V is the Voltage

The previous version of the kicker had a 20.8 J, and this means that an increase of over 160% was achieved. In order to find the optimum point of the coil's dimension, it is important to consider the following formulae:

$$E_L = L \cdot \frac{di}{dt} \qquad [3]$$

where: E_L is the voltage at the coil's terminals
L is the coil's inductance
di/dt is the current variation at the coil

E_L is obtained from a capacitor's discharge in a coil. The important factor is the coil's current, since that is directly associated with the force.

It is important to say force varies according to the core position inside the coil.

A simulation was carried out with this coil and discharge circuit, and the peak of current was calculated to be approximately 30A.

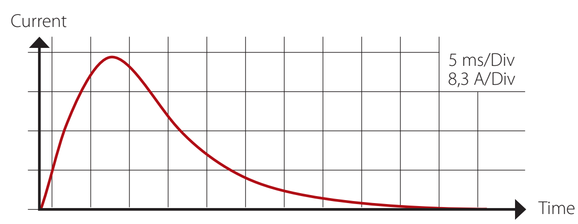

Figure 3. Current in the coil during capacitors discharge.

What limits the current in the coil is its resistance and its inductance. The coil resistance lowers the performance since it represents loss of power due to thermal effects, meaning though that it should be reduced up to a minimum. The wire cross section chosen used for the coil must be such that the voltage drop should be neglectable.

The main characteristic of the coil is the inductance, which in fact controls the current discharge. The inductance should not be too high to limit too much the current in the coil, nor too low to avoid large currents. If the discharge current becomes too high it will destroy the switch discharge component (N-MOSFET) and/or the capacitors.

An inductance of approximately 50 mH was chosen to this kicker due to current limitation of the electronic components used. The coil presented a 6 Ω resistance, which seams to provoke acceptable losses.

3.2 Capacitor's charge method

The previous versions of the kicker would charge fifteen 10 mF electrolytic capacitors. First, the voltage from the batteries was raised to up to around about 250 V, and in that way the capacitors were charged. The step-up used could not feed too much current. Therefore, the capacitors charge would take too long to achieve maximum power.

In order to improve this version of kicker, it can charge the capacitors in much less time (around about 2 seconds), and above all in a much safer way because there is no high voltage in the robots when they are turned off, even though the capacitors remain charged. The technique consists of charging all the capacitors in parallel, with only the voltage available on the batteries. This way, the capacitors charge can be very quick. Then, it is only necessary to convert the parallel circuit of the capacitors into a serial circuit. The voltage obtained from the serial link is the voltage multiplied by the number of capacitors.

Figure 4 shows how the circuit converts from a parallel link into a serial link.

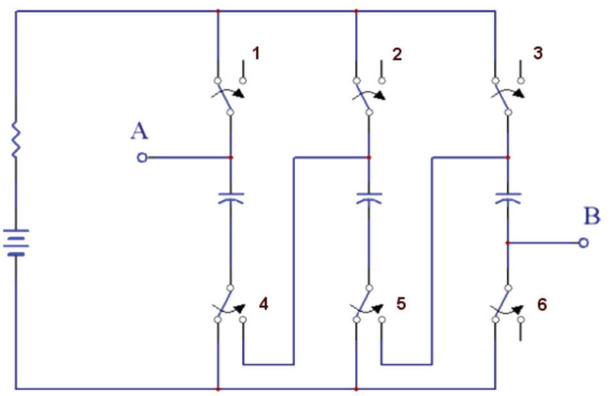

Figure 4. Change from parallel to serial capacitors link circuit.

The resistor is used to limit the capacitors charge current. The charging time depends on this resistor. To start the charging process, the switches must be in the position pictured on Figure 4. To connect them in serial they must switch to the opposite position.

The high voltage used to the coil discharge is taken from A and B. It uses 36V to charge all the capacitors.

4. KICKER CIRCUIT'S

The kicker is made up of 3 distinct circuits even though dependent of each other. These are: the charging circuit, the discharge circuit and the control circuit.

4.1 Charging circuit

The capacitor charging circuit is responsible for linking the capacitors in parallel ready to be charged and in the end connects them in serial.

The switches used in this circuit are relays. These have the advantages of working with high voltages and they avoid the use of optocoupler. When each relay is activated its respective LED goes on. The circuit is also protected by a fuse, and contains another LED, which indicates if the board is on. Since this is a research team and the circuits are under development, all these LED's are used to facilitate the detection of faults and to help debug process. The commands input are made through flat cable.

To avoid problems when switching between parallel to serial capacitors link, the order for turning on the relays is of extreme relevance. The relays 4, 5 and 6 must be switched some time before the relays 1, 2 and 3. The parallel to serial capacitors link switching order is made in reverse order. This way it is guaranteed that no capacitor is short-circuited during switching. It also allows charging only the desired capacitors, in order to reduce the serial total voltage.

4.2 Discharging circuit

This circuit is responsible for performing the current injection in the coil. It has to support high voltages and currents. The signal is output from the command circuit through a flat cable and an optocoupler is used to achieve insulation between the high power and the control. A power N-MOSFET is used to discharge the current through the coil, and a fast power diode is used for the coil freewheeling when the N-MOSFET is turned off. The circuit design is shown on the next Figure.

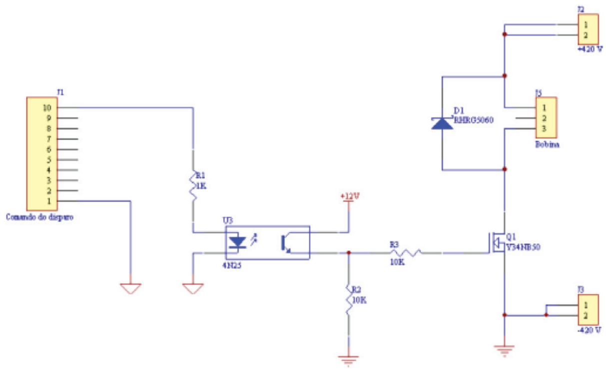

Figure 5. Discharging Circuit Design.

4.3 Control circuit

The control circuit (which can be called "kicker's brain") is responsible for the correct capacitors charge and for the preparation of the capacitors for the discharge process. It is this board that receives the instructions from the personal computer and determines the kicker's power that is to be used.

This board has the capacity to command simultaneously two capacitor boards. The connection to the capacitor boards is made with a *flat cable* of 10 wires. Like the other boards, it is also protected by a fuse and has a LED to indicate it is on. This board is responsible for sending out the command to kick. At the circuit heart there is a micro-controller (PIC16F84). It allows controlling parameters like kick power, the capacitors to charge, its sequence and desired charging time. All these parameters can be modified for each kick through simple instructions given by the computer.

4.4 Kicker characteristics

A picture of the kick can be seen in Figure 6. Table 1 shows its main characteristics.

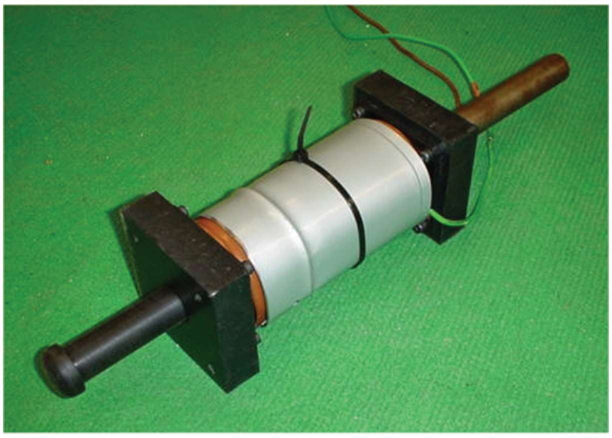

Figure 6. Photograph of the Kicker.

Table 1. Kicker Characteristics.

Characteristics	
Max. charging time	1.5 seconds
Max. voltage discharge	420 Volts
Equivalent capacitance	833 μF
Coil inductance	55 mH
Coil resistance	6 Ω
Max. energy consumption by kick	54 Joule
Weight	2 Kg
Ball distance	50 meters (approx.)

5. CONCLUSIONS

A kick is essential for successful robotic football. It should be strong, safe, energy saving and reliable. The kicker described in this paper is still under development and consists of an improvement from previous versions. It proved to be strong, feasible and with acceptable consumption.

When a kick is performed, it is fast recharging (less than 2 seconds) which means that another kick can be performed straight away. If the capacitors are not fully charged, it still kicks although not with the maximum strength.

When comparing this kick with previous versions, it uses more voltage and it is stronger. It also allows controlling the time the current passes through the coil which means it is possible to control the kicking power. The contact point at the ball and the kicker's end shape were also improved from previous version.

It is important to point out that a strong kick is not the only requirement for a successful team. The strategy is more important. The kick is only a shortcut for more goals if the robot is properly pointing towards the goal. It is controlled by software and that means that should the software not ask for a kick it will not kick.

In future, safety will have to be considered although at the moment this kick is not strong enough to destroy any robot or to hurt a human.

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