DETECTION OF BREAKTHROUGH DURING BONE-DRILLING IN ORTHOPAEDIC SURGERY

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Abstract:* Detection of breakthrough during bone-drilling for orthopedic surgery attempts to solve the problem of major tissue damage during bone drilling. Because orthopedic surgery often requires the drilling of bones, this concept of drilling will improve the accuracy of orthopedic surgery. In orthopedic surgery the bone-drilling used very often and it is performed by hand drilling in past, which causes a lot of problems—getting the big outlets, breaking the tendons or blood vessels, protecting the rear bone wall (which brings one more cutting of the tissue) and overheating. Previous bone-drilling systems have used speed control in both the feed platform and the drilling motor. This technique takes a different approach for the drilling motor and feed rate control in a bone-drilling system. The goal of this technique is to realize a control system that drills with monitoring of drilling motor current and can automatically stop drilling at the moment of breaking through and come back to its original position. This technique is based on the drilling torque measurement using current sensor. Stepper motor is driven by micro-stepping motor driver using current draw feedback. The proposed bone-drilling technique is more efficient and can be operated at a higher speed.

***Index Terms:* Orthopedic surgery, Bone-drilling, Current sensor, Torque measurement, feed rate control.**

I. INTRODUCTION

The main aim behind this idea is to develop a detection method of breakthrough when drilling bones in orthopedic surgery using drilling system. Bone fracture treatment commonly involves drilling of bone to produce hole for the screw insertion to fixate the fracture devices and implants. Current drilling tools do not include any means for the control of the penetration and only radiographic control and a surgeon's manual skill are used to arrest the penetration of the drill when the hole is completed. Late detection of bone/soft tissue breakthroughs can cause unnecessary major damage to the patient.

In orthopedic surgery the manipulation "bone drilling" is used very often and it is performed by hand drilling, which causes a lot of problems—getting the big outlets, breaking the tendons or blood vessels, protecting the rear bone wall (which brings one more cutting of the tissue), overheating and so on. The goal of this research study is to develop and validate experimentally a model for the description of breakthroughs during the penetration of bone. Such a model can be used for real-time detection of breakthroughs and be included in a mechatronic drill.

In this model current sensor is used for real-time detection of breakthrough. One of the most common applications for induction current sensing is motor monitoring. Because current draw is such an excellent indicator of motor condition, the current sensor can be used to solve a wide range of process control, safety, and maintenance problems.

The goal of this idea is to realize a control system that is able to drill with a feedback system, by taking advantage of both the drilling motor current and drilling torque signals, and that can automatically stop drilling at the moment of breaking through and drilling module go back to its original position using stepper motor. In particular, the feed rate is computed according to system impedance with this drilling motor current feedback.

II. PROPOSED SYSTEM

The proposed block diagram of this bone-drilling system is shown in figure 1, and it consists of a DC drilling motor with 3.5mm drill bit, a current sensor, signal buffer, amplifier, comparator, a drill feed unit (rack & pinion and stepper motor) with micro-stepping stepper motor driver, microcontroller, LCD and buzzer.

A. THE DRILLING AND SENSING MODULE

The drilling and sensing module is basically consisting of a DC drilling motor with a drill bit and a current sensor. In this system we are using 1500rpm 12V DC Drilling motor and 3.5mm drill bit. This drilling combination is main part of our system that comes into direct contact with the bone. We are using 1E/10W current sensing resistor as a current sensor in our system. So series resistor (1 ohm) system is used to sense the drilling motor current.

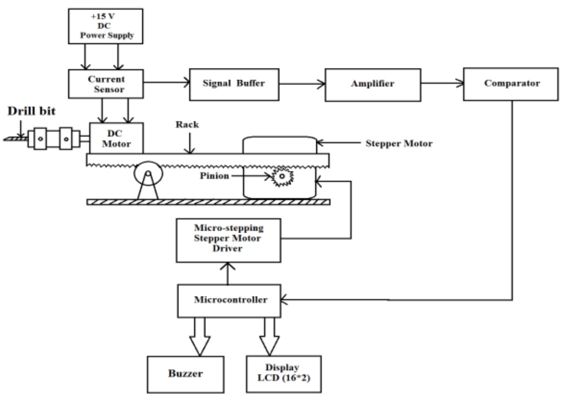

Fig. 1. Block Diagram of Proposed System

The current sensor (1E/10W Current Sensing Resistor) is located between the 15V DC power supply and DC drilling motor. As stated by ohm's law, there is a voltage drop across any resistance when current is flowing. A current sensing resistor is designed for low resistance so as to minimize the power consumption. This resistor, often referred to as a "shunt" resistor, is used to monitor the current in a circuit and translate the amount of current in that circuit into a voltage that can be easily measured and monitored. So we can simply say that current sensing resistors convert monitored current to a proportional AC or DC voltage or milliamp signal. That voltage signal is directly proportional to the current draw from the drilling motor.

Relation between current draw form drilling motor and motor load torque is linear. With increasing the load on motor, current draw increases. Current draw vs. load torque graph is shown in figure below.

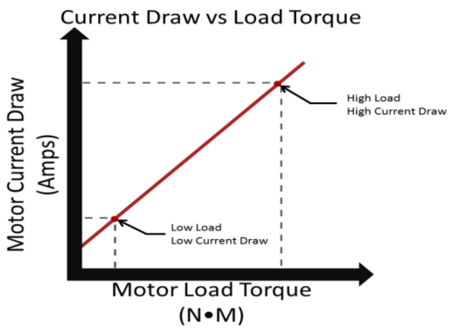

Fig. 2. Current Draw vs. Load Torque Graph

If there is high load then current draw from drilling motor is high and if low load then low current draw. This small current sensing device has extremely low insertion impedance so further processing of analog signal is required.

B. PROCESSING MODULE

Processing module is consisting of signal buffer, amplifier and comparator. Here we are using LM358 IC to fulfill the purpose of these three processing part.

For signal buffer and amplifier, two sections of LM358 IC are used in our system. A signal buffer amplifier (simply called a buffer) provides electrical impedance transformation from one circuit to another. There are two basic types of buffer: the voltage buffer and the current buffer. Here we are using voltage buffer for our purpose. A voltage buffer amplifier is used to transfer a voltage from a first circuit, having a high output impedance level, to a second circuit with a low input impedance level.

An amplifier is used to increase the power of a signal. It does this by taking energy from a power supply and controlling the output to match the input signal shape but with larger amplitude. So we can say an amplifier modulates the output of the power supply. It is very necessary for our system as it regards with accuracy.

A comparator is a device that compares two voltages or currents from current sensor and outputs a digital signal indicating which is larger. It has two analog input terminals V_+ and V_- and one binary digital output V_o.

A comparator consists of a specialized high-gain differential amplifier. They are commonly used in devices that measure and digitize analog signals, such as analog-to-digital converters (ADCs), as well as relaxation oscillators. For comparator only one section is used from LM358 IC. In this system digital output signal from comparator is fed to the microcontroller which contains the information about current draw in drilling motor.

C. MICROCONTROLLER

The microcontroller to be used in this research is AT89S52. The AT89S52 is a low-power, high-performance CMOS 8-bit microcontroller with 8Kbytes of in-system programmable Flash memory. The device is manufactured using Atmel's high-density nonvolatile memory technology and is compatible with the industry- standard 80C51 instruction set and pin out. Microcontroller manipulates the signal obtained from the sensor and feeds output to the display, buzzer and micro-stepping stepper motor driver.

The microcontroller also gives command to the stepper motor via motor driver according to the designed program for microcontroller like manually forward/reverse mechanism and auto drill. By pressing MANUAL FORWARD/REVERSE buttons we can move drilling mechanism in forward/reverse direction manually and if we press AUTO button then drilling module will work automatically. If the drilling motor current drastically decreases then stepper motor will stop at the moment and will come back to its original position.

D. DRILL FEED UNIT

The drill feed unit consist of rack & pinion mechanism, stepper motor and micro-stepping stepper motor driver. This unit is firstly driven by a stepper motor through a rack & pinion and the stepper motor is driven by a micro-stepping stepper motor driver.

We are using rack & pinion of 0.4module for better accuracy. Distance between each pitches of rack & pinion is 1.25mm, which is very small and efficient for our application and provides smooth movement. Internal diameter of pinion is about 5mm and outer diameter is about 10mm, which is specially designed for this system.

We are using a NEMA17 stepper motor (RMCS-1006) to provide micro-stepping for our drilling module. This stepper motor is manufactured by Robokits India limited. We choose this model because it is low cost, easily available and has sufficient torque to move our rack with drilling motor.

Normal DC gear-head motors require current greater than 250mA. IC like AT89s52 Microcontroller cannot supply this amount of current. If we directly connect motors to the output of our IC then they might get damaged. There is a need of a circuitry that can act as a bridge between the above mentioned IC and the motors. We are using micro-stepping stepper motor driver which is also manufactured by Robokits India Limited for very small, accurate and stable movement of our stepper motor.

E. LCD AND BUZZER

LCD is connected to the microcontroller; initially the state of drilling module is obtained on it like "PRESS AUTO OR

FORWARD/REVERSE". Microcontroller also sends digital signals to the LCD at the time of breakthrough and the message will display on it like "TISSUE DETECTED".
Buzzer is also connected to the microcontroller. At the time of breakthrough buzzer will ring to alert the surgeon during operation. It will continuously ring till the drilling module come back to its original position via stepper motor. Finally when drilling module come back to its original position buzzer will automatically stop.

III. CIRCUIT IMPLEMENTATION

Circuit implementation basically includes current sensing circuit, LM358 IC, micro-stepping stepper motor driver circuit, power supply circuit and crystal oscillator circuit.

A. CURRENT SENSING CIRCUIT

Current sensing circuit includes 12V 1500rpm DC drilling motor, 1E/10W resistor, 1000uF capacitor and a ferrite coil (inductor).

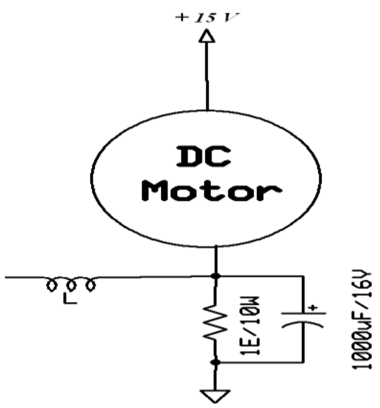

Fig. 3. Current Sensing Circuit

100uF capacitor is used for stable power supply and high frequency ferrite coil is used to cut the high frequency noise. Then the analog signal is forwarded to LM358 IC for further processing.

B. LM358 IC

LM358 IC includes a pair of amplifiers. For our system we are using two LM358 ICs and using three amplifiers of it. First IC is used as signal buffer and amplifier. Second IC is used for comparator for our system. We can see the pins of LM358 IC in figure below. For our application pin 2 and pin 3 are used for signal buffer inputs. Pin 1 is the output of signal buffer and pin 4 is grounded.

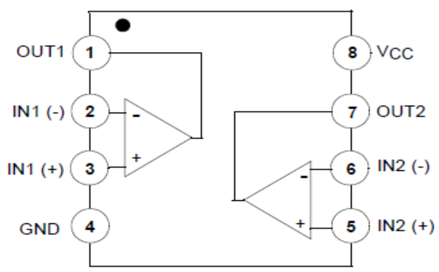

Fig. 4. Internal Diagram of LM358 IC

Output of signal buffer is fed to the amplifier at input pin 5. Pin 7 is the output of amplifier and pin 8 is Vcc. Output of amplifier is forwarded to the next LM358 IC as an input of comparator.

C. MICRO-STEPPING STEPPER MOTOR DRIVER CIRCUIT

Micro-stepping stepper motor driver circuit is advanced micro-stepping drive designed for smooth and quiet operation without compromising on torque and control at higher speeds. It has short-circuit protection for the motor outputs, over-voltage and under-voltage protection and will survive accidental motor disconnects while powered-up.
The RMCS-1104 achieves micro-stepping using a synchronous PWM output drive and high precision current feedback and this is absolutely silent when the motor is stopped or turning slowly. It virtually eliminates stopped-motor heating regardless of power supply voltage.
The RMCS-1104's closed-loop control gains are calibrated on start-up based on motor characteristics and also adjusted dynamically while the motor is in motion. This control algorithm makes it capable of achieving better torque at higher speeds in comparison to comparable drives in its range.

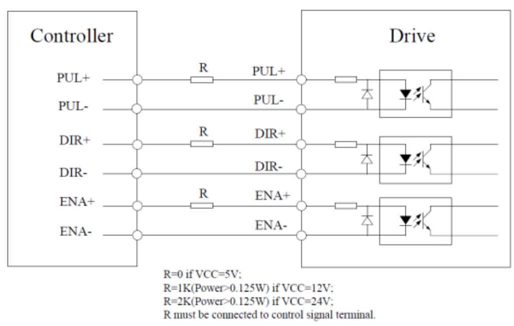

Fig. 5. Differential Control Signal Connection

The above figure shows internal control signal connection in differential method. The PULSE/STEP, DIRECTION inputs are optically isolated. Both inputs work with 2.5V, 3.3V or 5V logic drive signals. The input drive current is 5mA at 2.5V so almost all logic family (74LS, 74HC, etc.) can be used to drive these inputs. Each input provides individual anode and cathode connections to the opto-isolator allowing for multiple input drive interfaces.

D. POWER SUPPLY CIRCUIT

The power supply is designed to supply the power to almost all the components in the given circuit diagram. The IC used to give +5V power as an output is LM7805. IN addition to this IC a full wave rectifier circuit is connected that converts the AC voltage to the DC voltage. Then this rectified voltage is fed to the LM7805 IC that gives us constant +5V power as an output.

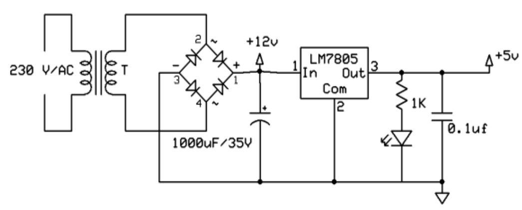

Fig. 6. Power Supply Circuit

LM7809: This IC has 3 pins. The pin 1 is an input pin that receives an input from the full wave rectifier circuit. The pin 2 is a COM pin that is used to provide ground to the circuit so that due to change in parameters the circuit does not gets affected. And the pin 3 is the output pin that provides us the required output voltage that is +5V.

E. CRYSTAL OSCILLATOR CIRCUIT

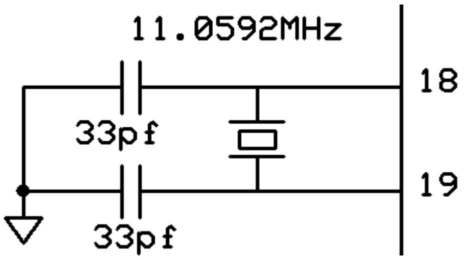

Fig. 7. Crystal Oscillator Circuit

A microcontroller/processor needs a stable clock to run. Provided the circuit and external capacitors are set up correctly, and located close to the XTAL pins on the micro, the crystal oscillator will oscillate at the specified rate. If the clock isn't stable you could encounter timing problems inside your micro. Violating setup and hold times will cause erratic behavior.

IV. RESULT

Drilling motor torque measurement is most important for our system because microcontroller program is designed based on its results.

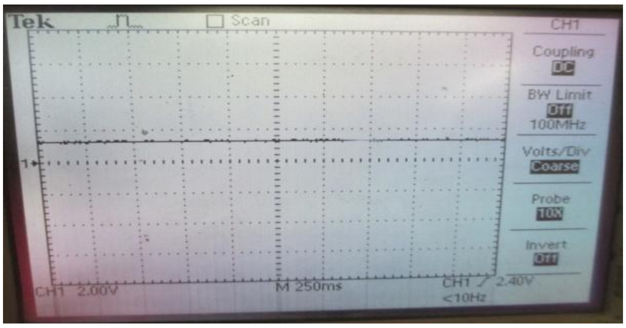

Fig. 8. Torque vs. Time Graph at Ref. Voltage

The above figure shows the torque vs. time graph at reference voltage across the system. We got this result at the output of LM358 IC. Reference voltage is set about 2 volts for our system.

When drilling module drills the hard demo material (bone), drilling motor torque goes to its peak level. At that time we got the result as shown in figure below.

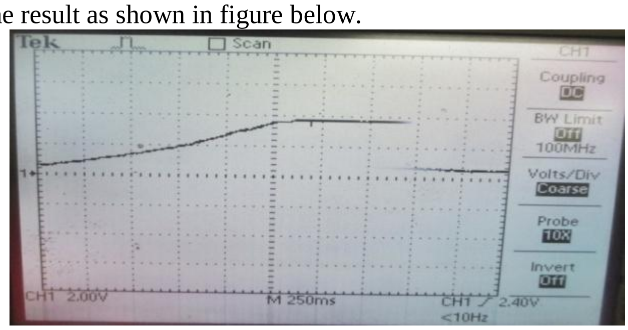

Fig. 9. Torque at Peak level

Finally at the time of breakthrough we got the graph of torque vs. time as shown in figure below.

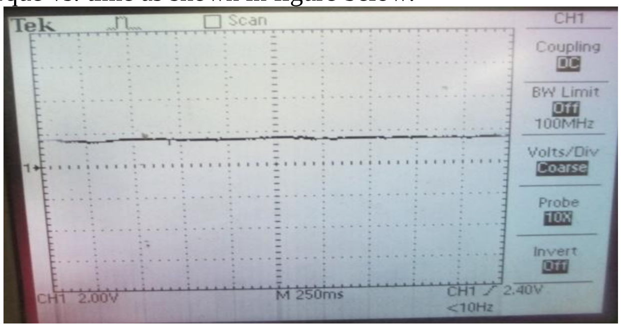

Fig. 10. Ending Low Torque

This final result is very important for our system because it gives the tissue detection information via torque signals. After detecting this phase drilling module will stop and come back to its original position automatically.

V. CONCLUSION

This work here by concludes that our system automatically stopping the feed and drilling module come back to its original position when it crosses a bone/soft tissue interface and when a dangerous situation is detected. Drilling motor torque measurement is main parameter of this system as it is used for the soft tissue detection. There is monitoring of the drilling procedure by means of sensor, in order to supply the surgeon with all the relevant information he/she may need in this system. The buzzer in our system is very useful as it alerts the surgeon at the time of breakthrough. There is strong reduction in the use of the X-ray during the intervention to monitor the tool position inside the patient's body and also reduction in the major damage of soft tissues surrounding the bone using our system.

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