Effect of electromagnetic induction spectroscopy of femur bone on electromagnetic signal strength

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Abstract. Bone implant is a promising technique to heal the fracture site where it focusing to stabilize and support the bone. Improvement in bone implant are required in order to ensure better healing process because some failures may happen due to the loss of implant stability. Previous studies showed there are lack of investigation on bone implant. Early detection of screw implant loosening is crucial for faster repairing and a healthy ready-to-operate. The purpose of this study is to investigate the signal strength of electromagnetic field induction on human bone by employing a single channel magnetic induction spectroscopy using flat spiral coil sensor. This study also to evaluate the various type of coil sensitivity of the magnetic induction spectroscopy on femur bone. The electromagnetic field induction will be analyse using the COMSOL Multiphysics simulation software to collect the data of received signal strength. The promising experimental results suggested the feasibility of the proposed electromagnetic induction spectroscopy.

Keywords: electromagnetic field, magnetic induction spectroscopy, bone implant, femur bone.

1. Introduction

Human bone is classified into two types which are cortical (dense and compact) and trabecular bone (spongy, honeycomb-like structure). Femoral (femur) bone is a cortical bone which have to be strong to support the body weight and daily routine activity. Human bone fracture is a common traumatism due to the aging population and the wide incidence of osteoporosis [1]. Proximal femoral Fractures account for a large proportion of hospitalization among trauma cases [2]. Fracture fixation used to stabilize the fractured bone, to enable fast healing of the injured bone, and to return early mobility and full function of the injured extremity [3]. In particular, implant failure remains a problem for unstable fractures, despite improved techniques and various implant modifications [4]. The use of magnetic induction in bone implant is discovered in this paper for further study to analyse bone implant failure in human bone.

The magnetic induction concept recognized as Electromagnetic Induction Spectroscopy (EMIS) was used to detect hidden metals and discriminate among the types of metals using multi-frequency approach based on metal’s unique Passive Electrical Properties (PEP) as well its geometry and shape [5]. The conductivities, permeability and permittivity values from the MIS system can be
used in medical diagnostic purposes which have been proved by H. Schafetter [6]. Magnetic induction spectroscopy (MIS) is actually a multi-frequency measurement version of the magnetic induction tomography (MIT) [7] where generated magnetic fields and its perturbed signals are gathered by receiver coils in the form of voltages \( V_0 \) and \( \Delta V \) respectively. Therefore, a voltage difference that is derived from the summation of both aforementioned magnetic signals collected from the receiver coil estimates the ultimate inductive phase shift. MIS technique was then further explored and developed towards detecting pathological conditions, the detection of jaundice in new born baby, a condition where applying magnetic field on baby’s finger to detect jaundice level by using transmitter coil and receiver coil which was studied in [8].

2. Methodology

Magnetic Induction Spectroscopy (MIS) and Magnetic Induction Tomography (MIT) has same principle which is the non-invasive measurement [8]. MIT normally applied to construct the change of the conductivity by using alternating magnetic fields in a specified object. The common used of MIT is for non-invasive monitoring for example, monitoring of edema in human brain [9]. Figure 1 below show the ideal concept of MIS system with a transmitter coil and its magnetic field around the coil penetrates into the object near it. To produce the magnetic field, MIS system required the transmitter and receiver coil as the sensor and applied current [10]. The received magnetic field gathered at the receiver was then calculated to measure the magnetic induction phase shift of the MIS applied on the model.

![Figure 1: Ideal concept of eddy current in a conductive material [6].](image1)

The flowchart in figure 2 shows the step-by-step of the process to detecting the magnetic induction phase shift of the bone by using the COMSOL Multiphysics software. The bone material is set in the software with a different conductivity and permittivity value based on the frequency used which shown in table 1 below. The properties of the coil which is the transmitter and receiver is shown in the table 1. The material used for the transmitter and receiver coil is a copper.

With respect to the MIS principle, when the coil excitation produced the magnetic field which is the primary field, another secondary field which is the eddy current will be induced in the conductive material which is the screw. Eddy currents build their own magnetic field but in the oppositely from the primary field excites from the coil (transmitter)[11]. In this case, currents is an important part as an alternating current which to be fed into the coil to generate magnetic flux around the coil.

Figure 3 below shows the geometry model of the simulation in COMSOL software where the transmitter and receiver is sandwiching the femur bone regardless MIS concept. 1mm gap between sensors (transmitter and receiver) and bone is assign to make it a non-contact measurement.
Table 1: Value of conductivity and permittivity of the femur bone.

| Frequency (MHz) | Conductivity | Permittivity  |
|----------------|--------------|--------------|
| 1              | 0.2122       | 759.7795     |
| 2              | 0.2162       | 686.9853     |
| 3              | 0.2169       | 643.3089     |
| 4              | 0.2203       | 577.7942     |
| 5              | 0.2264       | 574.1545     |
| 6              | 0.2267       | 559.5956     |
| 7              | 0.2279       | 541.3971     |
| 8              | 0.2243       | 526.8383     |
| 9              | 0.2273       | 519.5589     |
| 10             | 0.2304       | 508.6398     |

By using the principle of MIS, spiral coil is used to generate magnetic field at the transmitter and the specification of this coil is very important to generate strong magnetic field to cross the screw which be the interest region and detect the changing of magnetic field strength at the receiver[12]. The range of frequency used in this simulation is 1MHz to 10MHz with 10 step of 1 MHz. Frequency in the range of hundreds kilohertz (kHz) region which occurs at intermediate frequencies is suitable for the MIS where it is common used in many detection in medical field using magnetic induction [10], [12]–[14]. MIS system for this simulation started when the applied current AC pass through transmitter and coil and primary magnetic field is produced[8]. Figure 4 below shows the simulation model with the magnetic field around the sensors.
Figure 3: Femur bone with the coils sensor.

Figure 4: Simulation model at 10MHz frequency.

Table 2: properties of transmitter and receiver coils.

| Types   | Properties          | Transmitter | Receiver |
|---------|---------------------|-------------|----------|
| Model 1 | Number of turns     | 5           | 5        |
|         | Current applied     | 1A          | 0A       |
|         | Coil diameter       | 10mm        | 10mm     |
|         | Wire diameter       | 1mm         | 1mm      |
| Model 2 | Number of turns     | 12          | 5        |
|         | Current applied     | 1A          | 0A       |
|         | Coil diameter       | 10mm        | 10mm     |
|         | Wire diameter       | 1mm         | 1mm      |

3. Result and discussion

Simulation process of the MIS system is done in COMSOL Multiphysics including the geometry design of coil sensor and femur bone. This system is perform in single channel magnetic induction and it’s useful to measure the total magnetic field strength. Single channel magnetic induction spectroscopy included with one transmitter and one receiver which is opposite to each other [10]. The graph below show the result from the simulation process of different model. Figure 5 below show the result of total magnetic induction phase shift between model 1 and model 2. Figure 6 and Figure 7 shows the effect of multi frequency 1-10MHz on the total magnetic induction phase shift for both model 1 and model 2.

Figure 5: Result of magnetic induction phase shift of different model.
From the graph above, the y-axis represent the total magnetic field (A/m) and the x-axis represent the frequency (MHz) used. The alternating current in the transmitter coil generate the electromagnetic field which is the induction field propagated within the femur bone. The generated eddy current which is the secondary field for magnetic field strength is measured at the receiver. As shown in figure above, the total magnetic field for model 2 shows the higher value compared with the model 1. This is because the higher the number of turns exhibits a higher intensity and more stable signal which cause the changes of total magnetic field strength is higher [15]. By differentiate these two models, it is explained that the higher the number of transmitter coils, the higher the magnetic field generated from the transmitter. When the magnetic field induces in the bone samples, it will generate higher magnetic induction phase shift.

4. Conclusion

Human body is a volumetric with a conductivity material and it made of from several tissues with different conductivity which make the Magnetic Induction Spectroscopy (MIS) easy to be implemented. The application of MIS have been widely used in medical purpose experiment to ensure the healing or health of human body is upgraded to a new level which can save a lot of particular parameter. MIS system can be implemented to human body and also the material of bone implant which bring to the failure of internal fixation can be identified on early stage.

5. Acknowledgement

The author would like to acknowledge the support from the Fundamental Research Grant Scheme (FRGS) under a grant number of FRGS/1/2017/TK03/UNIMAP/02/10 from the Ministry of Higher Education Malaysia.

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