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Primary experimental study on safety of Deep Brain Stimulation in RF electromagnetic field

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Abstract—**With the rapid growth of clinical application of Deep Brain Stimulation, its safety and functional concern in the electromagnetic field, another pollution becoming much more serious, has become more and more significant. Meanwhile, the measuring standards on Electromagnetic Compatibility (EMC) for DBS are still incomplete. Particularly, the knowledge of the electromagnetic field induced signals on the implanted lead is ignorant while some informal reports some side effects. This paper briefly surmised the status of EMC standards on implantable medical devices. Based on the EMC experiments of DBS device we developed, two experiments for measuring the induced voltage of the deep brain stimulator in RF electromagnetic field were reported. The measured data showed that the induced voltage in some frequency was prominent, for example over 2V. As a primary research, we think these results would be significant to cause researcher to pay more attention to the EMC safety problem and biological effects of the induced voltage in deep brain stimulation and other implantable devices.**

I. Introduction

Deep brain stimulation(DBS) is using implantable electrical stimulation pulse to treat neurological disorders. Since 1995, DBS was used in curing tremor, Parkinson's Disease (PD), dystonia and obsessive compulsive disorder (OCD), there are about 55,000 people all over the world have accepted this therapy. Besides, the DBS has the foreground to be used in treatment of depression, drug addiction etc [1].

As the fast development of wireless communication and personal electronic devices (such as cell phone, Personal Digital Assistant etc) in the past decades, electromagnetic radiation is covering almost everyone's daily life. The DBS system is sensitive electronic device in RF electromagnetic field. Inevitably, it will be disturbed by the RF radiation. And sometimes the extension and the lead of DBS will be as long as 91cm total, which will act as an antenna in RF electromagnetic field (as shown in Fig.1). With the wide application of DBS, its safety in RF electromagnetic field should be carefully studied. And several clinic examples have found that some patients who received DBS therapy have suffered severe descending of curative effect in daily RF electromagnetic field, such as cell phone radiation, massage machine radiation etc.

Many studies have focused on the safety of DBS in electromagnetic field, especially in Magnetic Resonance Imaging (MRI), because the patients who accepted DBS will always need MRI to make sure the position of electrode. David W. Carmichael et al studied the DBS's temperature and the induced voltage between IPG case and one of its electrodes in MRI [2]. Kenneth also studied the temperature change of DBS in MRI [3]. C. Pollo et al studied the Magnetic resonance artifact induced by the DBS electrode in MRI [4]. Some researches have done focusing on the safety of active implanted devices in RF electromagnetic field. Lisheng Xu el al studied the radiation characteristics of ingested wireless device at frequencies from 430 MHz to 3 GHz [5]. Stevenson R A et al designed an Electromagnetic interference filter terminal to protect the cardiac pacemaker's circuit from unwanted induced voltage interfering [6]. Hrdlicka et al designed a filter device for use in implantable pulse generator to reduce the induced voltage to protect the system from daily life electromagnetic radiation [7].

In addition to the academic researches, many organizations have also released standards to ensure the safety of implantable stimulators in RF field. The International Standard Organization released the document ISO 14708-3:2008 to regulate the EMC of the implantable neurostimulator[8]. American Association for the advancement of Medical Instrumentation has released the ANSI/AAMI PC69:2007 to regulate the active implantable medical devices [9]. European standard EN45502-1:1997[10] also concerned the EMC of active implantable medical devices.

However, there are few researches studying the safety of DBS in RF electromagnetic field, including DBS's working stability and patients' safety. By now there are even no reference data about how high the induced voltage in DBS electrode will be. The current research designed two experiments to test the induced voltage in the DBS lead in 80M~500MHz RF field. The test results showed that the induced voltage has significantly amplitude to the patients.

II. Question

Generally DBS system includes three parts[11]: implantable pulse generator (IPG), extension and lead, as shown in Fig. 1. IPG produces the stimulation signal, and this signal is introduced to the therapy point of patient's nerve system by the use of extension and lead, such as subthalamic nucleus (STN) or internal globus pallidus (GPi)in curing PD[1,12]. Fig.2 showed a typical DBS stimulation pulse [12] (The pulse width is 90us. Pulse frequency is 150Hz, and pulse amplitude is 1.5V).

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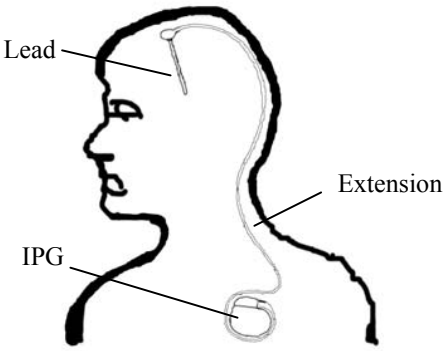

Fig. 1. DBS system

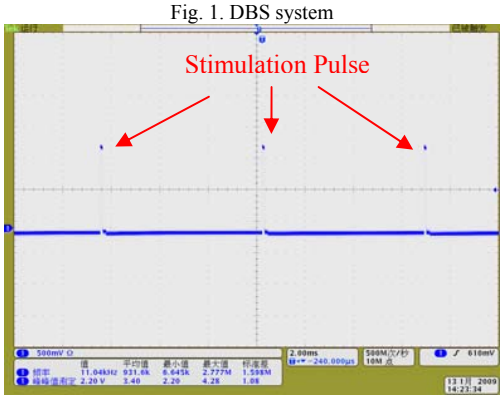

Fig. 2. Stimulation pulse

In the RF field, the DBS system will respond to the external electromagnetic filed. Two questions should be taken into account:

1) Because the IPG is sensitive electronic device, RF field may cause the IPG resetting, stop-working, system damage or other decreasing of performance. For the sake of safety, the stability of IPG in RF field should be carefully evaluated. As for these questions, there are many ways to test and evaluate the stability of IPG in RF filed, such as using IPG's software to record the system's running state and working history when it is working.

2) The DBS system will induce signal in RF field, and this signal will be introduced to the therapy point together with the stimulator pulse. The therapy point is sensitive to electrical signal; hence the stimulating effect and the safety of the induced voltage to patients should be carefully studied.The amplitude of the induced voltage is determined by many factors: the intensity and the direction of the electromagnetic field, the characteristic of the IPG, the length of the extension and lead etc.

As a new method to treat neurological disorders, the deep brain stimulation is still in development. Limited scholars have paid attention to the induced voltage of DBS in RF field. Until now there are few studies have done about testing the induced voltage in DBS, and it is difficult to test the induced voltage in RF field because the test equipments will always be interfered by RF radiation.

As we referred above, many organizations, such as the ISO, AAMI and CE etc, have released standards concerning the safety of active implantable medical devices, and some clause of them have concerned to test and evaluate the EMC safety in RF electromagnetic field. But there are still two problems in these standards:

1) All these standards mainly focus on evaluating the stability of active implantable device, less clause focus on testing of the induced voltage. Some clause mentioned this problem, but the test methods are vague and have less maneuverability. Such as ISO14708-3 Clause 27.105, as for the testing of the stability in electromagnetic fields in the range 30MHz~450MHz, it pointed out "Neurostimulator output can be monitored by using an oscilloscope to a sense resistor in series with the lead or by using another lead placed into the saline as a pickup lead". Actually in the field experiment, the oscilloscope will inevitably be interfered by the RF electromagnetic, so the test result is unbelievable, and this test method has less maneuverability.

2) The induced voltage is unavoidable in the DBS lead, and it will be introduced to the therapy point. As for the safety value of the induced voltage, there are no common criteria until now. Even now there are no reference data about how high the induced voltage will be.

In the next part of this paper, we reported two designed experiments to monitor the induced voltage of the implanted stimulators in RF field between 80M~500MHz.

III. EXPERIMENT

In this section we tried to test the induced voltage of DBS in the RF field. The test RF electromagnetic field was based on standard IEC 61000-4-3[13]. The DBS device we used in this experiment is a unilateral subthalamic stimulator which developed by Tsinghua University of China. The animal trial by stimulating hemiparkinsonian rhesus's GPi has been finished in Beijing Tiantan Hospital, the safety and effectiveness of this DBS have been confirmed in all the four monkeys. The clinical research is being prepared according to the medical device registration guide of State Food and Drug Administration P.R. China (SFDA).The DBS output pulse parameters in our experiments was listed as below: Pulse width is 90us, pulse frequency is 150Hz, and pulse amplitude is 1.5V.The layout of IPG, extension and lead is according to ISO 14708-3, clause 27.105[8]. At the end of the DBS's lead, a 1KΩ resistance was connected to the electrode as load.

A. Test of induced voltage in RF field of 80M~200MHz

In this experiment, we used an electric-optic converter in the anechoic chamber to convert the electrical signal of the stimulators' output to optical signal, and transferred this optical signal to the outer of the anechoic chamber by a fiber optic cable (as shown in Fig.3). In this way, the test equipments were avoided to be interfered by the RF electromagnetic field. At the outer of the anechoic chamber, we used an optic-electric converter to convert the optical signal to electrical signal, and monitored the electrical signal by an oscilloscope (Tektronics MSO 4104). This experiment was carried out by two steps.

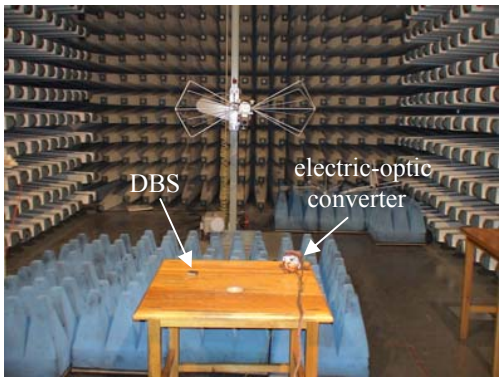

Fig. 3. Test condition 1

1) Firstly, we removed off the DBS to test the voltage induced by the test equipments. Experiment results showed that the induced voltage in the test equipments is lower than 5mV. It means that the electric-optic converter has a good electromagnetic shielding.

2) Secondly, we connected the DBS with the test equipment, to test the voltage induced by the whole system. Obvious induced signal can be observed in the oscilloscope during the experiment process. Fig. 4 is one of the results of the experiment. Here the peak to peak value of induced voltage is about 300 mV. In the whole experiment process, the maximum peak to peak value of induced voltage is 1.8V when the electromagnetic is 3V/m and 2.0V when the electromagnetic is 10V/m. Some of the data recorded in this experiment is listed in Table I.

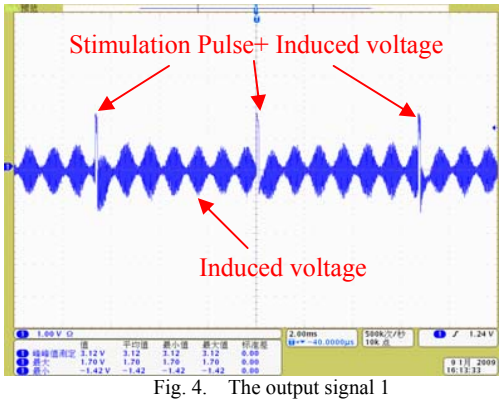

Fig. 4. The output signal 1

TABLE I

TEST RESULT OF BANDWIDTH 80M~200MHZ

FREQUENCY (MHZ)	DIRECTION OF ELECTRIC FIELD	ELECTRIC FIELD INTENSITY (V/M)	THE PEAK TO PEAK VALUE OF INDUCED VOLTAGE(V)
80	Vertical	10	1.5
80	Vertical	3	0.5
80	Horizontal	10	0.5
80	Horizontal	3	0.5
100	Vertical	10	2.0
100	Vertical	3	1.5
100	Horizontal	10	2.0
100	Horizontal	3	1.8
120	Vertical	10	1.0
120	Vertical	3	0.5
120	Horizontal	10	0.8

B. Test of induced voltage in RF field of 200M~500MHz

Considering the bandwidth of the electric-optic converter we used is about 200MHz, we should use another way to test the RF field above 200MHz. In this experiment, we used two parallel shield copper cables to transfer the electrical signal to the outer of the anechoic chamber, as shown in Fig.5. At the outer of the anechoic chamber we monitored this electrical signal by an oscilloscope (Tektronics MSO 4104). Considering the copper cables will be interfered by electromagnetic field, the test results should take this case into account. This experiment was carried out by two steps.

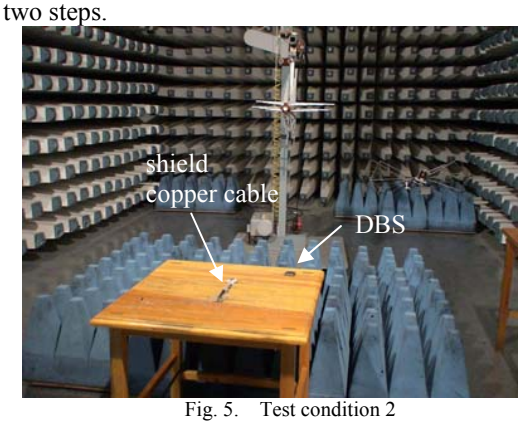

Fig. 5. Test condition 2

1) Firstly, we removed off the DBS, tested and recorded the voltage induced by the test equipments. Notable induced signal can be observed in the oscilloscope during the experiment process. In the frequency of 200M~500MHz, the maximum induced voltage in the shield copper cables is about 0.3V while the field intensity is 10V/m.

2) Secondly, we connected the DBS with the test equipment, to test the voltage induced by the whole system. In the experiment, the induced signal can be observed in the oscilloscope. Fig. 6 is one of the results of the experiment. In the frequency of 200M~500MHz, the maximum induced voltage is about 3V when the field intensity is 10V/m. Minus the voltage induced by the shield copper cables, the maximum induced voltage in the DBS is about 2.7V. Part of the data recorded is listed in Table II in which the electric field intensity is 3V/m.

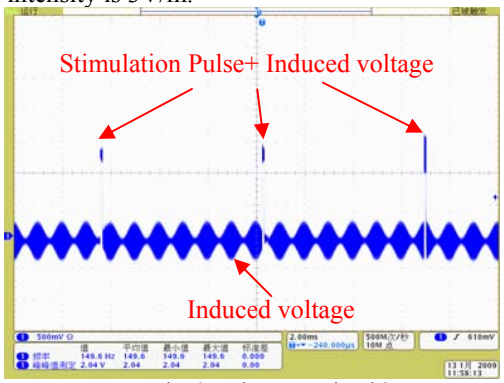

Fig. 6. The output signal 2

TABLE II
TEST RESULT OF BANDWIDTH 200M~500MHZ

FREQUENCY (MHZ)	THE PEAK TO PEAK VALUE OF INDUCED VOLTAGE(V)	FREQUENCY (MHZ)	THE PEAK TO PEAK VALUE OF INDUCED VOLTAGE(V)
205	1.2	280	1.5
212	1.5	288	1.4
216	1.7	300	1.2
220	1.5	315	0.8
236	0.9	328	0.7
243	0.8	363	0.8
248	0.9	429	0.6
253	1.0	460	0.5
260	1.1	470	0.5
264	1.3	485	0.5
274	1.5	490	0.5

IV. DISCUSSION

By the experiments above, we can find notable interfered voltage in DBS lead. The maximum induced voltage found is 1.8V when the electric field intensity is 3V/m and 2.7V when the electric field intensity is10V/m. The induced voltage will be introduced to the therapy point by the lead. The amplitude of the induced voltage is high enough to produce stimulating effect to the patient (Generally speaking, the DBS pulse amplitude is less than 3V), but its frequency is high, how human body will respond to this high frequency induced voltage is not known until now.

The voltage e induced by Faraday law:

$$e = \oint_l E_i \cdot dl = -\frac{d}{dt}\int_s B \cdot dS$$

Here, l refers to the loop length of extension and lead. S means the loop area of extension and lead. E_i means the electric field intensity of the electromagnetic field, B means the magnetic flux density of the electromagnetic field. In DBS system, extension and lead contain four independent metal wires, two of them will form loop while working. The induced voltage was determined by the area of this loop. The distance between each two wires is about 1mm, assume the extension and lead is 91mm, the area loop is about 200mm^2, including the connecting area between the IPG and the extension and the area between the extension and the lead. There are two ways to reduce the induce voltage: a) reduce the length of extension; b) reduce the loop area, such as twisting the four wires.

By the experiments, we can also find that the IPG is steady in the electromagnetic field, whenever the field intensity is 3V/m or 10V/m. In the whole experiment, no reset of the IPG system was found, and no any malfunction was found. This may due to the titanium shell of the IPG acts as an attenuator to the external electromagnetic energy.

Because lacking of equipments to transfer signal over 500MHz to the outer of the anechoic chamber effectively, we only tested induced signal in frequency of 80M~500MHz in this research. Nowadays many personal communication devices are using higher frequency, such as GSM cell phone is using 900MHz carrier. Bluetooth device is using carrier frequency about 2400MHz. More experiments to test the induced voltage over 500MHz need to be done in future.

In addition, these two experiments were carried out in air condition. After the DBS implanted into human body, the induced voltage will be lower than these experiment results, because human body will absorb part of electromagnetic energy. In future experiments, the DBS should be put into a saline bath of conductivity 0.27S/m to test induced voltage.

V. CONCLUSION

Through the experiment and the above results analysis, the DBS system has shown its stability in RF electromagnetic filed, there is no reset and no malfunction appeared. However, the DBS system will induce voltage. The maximum induced voltage is about 2.7V (peak to peak value).This induced voltage will be introduced to the therapy point by the DBS's lead. That how this induced voltage will influence the patients is still necessary to be carefully studied in future research.

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