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The characterization of NMR signal for blood pressure monitoring system and its testing

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ABSTRACT

A blood monitoring system based on NMR method has been designed on constructed. This set-up of equipment used magnetic permanent, radio frequency (RF), receiver coil (RC), function generator (FG), amplifier which included the filter, as well as the oscilloscope digital storage. The background of this research was based on the sensitivity of NMR signal. The signal must be separated from signals background. This method was done by adjusting the frequency on FG, which was connected to radio frequency (RF) coil, on empty sample. Subsequently, NMR signal was received by RC, and that signal could be shown on oscilloscope at resonance condition. The true frequency on NMR signal was Larmor frequency, and the other was background. The two variables of this experiment were the position of RF coil and the location temperature (20 up to 30^{o}C). In conclusion, the resonance frequency of NMR signal (as Larmor frequency) was 4.7 MHz (at static magnetic field of 1,600 gauss) and it could be separated from background signals (3.4 and 6.2 MHz), and that signal was almost constant to room temperature. The equipment was used for sample testing. It gave systole/diastole data of 110/70 mmHg (on sphygmomanometer) that was similar to 17/9 mV (on NMR signal).

ABSTRAK

Telah dikembangkan alat pemantauan tekanan darah berdasar prinsip NMR. Pada riset ini diselidiki, apakah sinyal yang muncul di layar osiloskop benar-benar berasal dari tekanan darah sampel (pasien). Teknik pengukuran ini melibatkan instrumen berupa: magnet permanen, koil radio frekuensi (RF), koil penerima (RC), *fungsion generator* (FG), *amplifier* beserta filternya, dan unit pemantau berupa *oscilloscope digital storage*. Penelitian ini dilatarbelakangi oleh adanya kekhawatiran bahwa sinyal NMR oleh nilai sistol dan diastol bersifat tumpang tindih dengan sinyal NMR oleh sumber lain atau latar. Penelitian ini dilakukan dengan meneliti sebaran kuat medan magnet di sekitar magnet permanen (B_o). Kemudian, pada kawasan frekuensi FG terpilih yang bersesuaian dengan nilai medan magnet statis guna menghasilkan sinyal NMR, ditampilkan sinyal NMR ketika koil RF kosong. Akhirnya, parameter sinyal itu dibandingkan dengan sinyal NMR ketika di dalam koil RF berisi lengan sampel. Hasilnya, frekuensi larmor oleh momen dipol magnet spin proton atom hidrogen (B_o = $(1{,}6 \pm 0{,}2)10^2$ gauss) pada aliran darah adalah berkisar 4,7 MHz. Sedangkan, frekuensi yang menghasilkan sinyal latar (tidak peka terhadap perubahan suhu lingkungan) bernilai 3,4 dan 6,2 MHz. Artinya, sinyal latar tidak berpengaruh

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terhadap sinyal NMR (oleh adanya tekanan darah arteri sampel). Dari uji coba, telah dapat ditampilkan pula sinyal NMR sampel 17/9 mV yang bersesuaian dengan sistol/diastol (diukur dengan sphygmomanometer) 110/70 mmHg

Keywords: NMR-characterization-blood pressure-monitoring-testing

INTRODUCTION

The relationships between physics and some applied sciences is increasingly close.[1,2] For example, the cooperation between physics and medical science is termed medical physics. Products of such cooperation are medical equipments. These equipments are designed and constructed using physics combined with medical information. One example of the medical equipment products is artery blood pressure monitoring system. The blood pressure is defined as the pressure in systemic circulation (heart – all organs – heart), but not that in small circulation (heart – lung – heart).[3] Systemic circulation is chosen because the arteries and veins of this circulation are through some vital organs such as brain and liver.

The blood pressure monitoring system could be categorized into two main methods, namely invasive and non-invasive methods. The invasive method could be carried out by placing a device inside the arteries. This method (such as that using catheter) is accurate, very small in the dimension of equipment, good for critical patients, but expensive. The non-invasive method is used by placing the equipment outside of body organs. This method is safe, the dimension of equipment is not small enough, but it could be mobile. Unfortunately, this method is frequently not precise. Therefore, this method could be used to monitor the health of people daily. Sphygmomanometer is one of the examples.

The operation principle of catheter is different from sphygmomanometer.[4,5] The blood pressure monitoring system of catheter is continuous, and it is based on the measurement of pulse blood flows. On the other hand, sphygmomanometer is based on the measurement of turbulant blood flows. This means that the flows of blood in patients are undisturbed in catheter measurement, but they are disturbed in sphygmomanometer measurement. The variances of blood pressure, which could be monitored, are systole/diastole, pulse on blood pressure, and the average of blood pressure. The systolic phase of blood pressure is caused by the contraction of the heart, and the diastolic phase is caused by the relaxation of the heart. The pulse on blood pressure is the value of systole subtracted to diastole. The average blood pressure is the average of systole-diastole in one period.[6,7]

We have previously carried out studies on blood pressure model using NMR.[8,9] The present study introduces a new technical method for blood pressure monitoring system using NMR.[10] The method applied in the current study, which is based on pulse of blood flows, is similar to catheter method, but non-invasive, safe, and cheap. These characteristics are similar to those of sphygmomanometer method. The present research aimed at calibrating NMR signals and test for the sample. It was carried out in 3 steps. The first step was to know and check the reality of NMR signals by blood flows in sampled arteries then it was compared to the background signals. The second step was to characterize the home made blood pressure monitoring system. The third step was to do a sample testing. It is expected that this home-made instrumentation could be used safely for blood pressure monitoring system.

MATERIALS AND METHODS

Nuclear Magnetic Resonance (NMR) signals could be found by the transition of "magnetic dipole moment of spin proton on atomic hydrogen" (mdmspah) from the higher energy level to the lower one.[11-14] This transition changes the magnetic flux on radiation. This magnetic flux radiation is received by receiver coil (RC). The transition of mdmspah from upper energy level to the lower one is called relaxation. The duration for relaxation is called relaxation time. A proton is a nucleus of hydrogen atom, and water molecule is dominated by hydrogen atoms. NMR process is based on mdmspah transition. Human organ is dominated by water, and therefore NMR process could be applied on every human organ. Thus, it could be used to detect the flows of blood in arteries.[15,16] The working principle of NMR device as blood pressure monitoring system is shown in FIGURE 1. FIGURE 1a presents a picture of fluid (as mdmspah inside blood) flowing from left to right. Initially, the direction of mdmspahs is random. Subsequently, at an area between two magnetic poles *N* (north) and *S* (south) at about 1,600 gauss, some of mdmspah are oriented to minimum on their potential energy. For a moment, mdmspah is radiated by electromagnetic (em) wave from radio frequency (RF) coil. This radiation causes some of mdmspah in excitatory condition. RF coil is connected to function generator (FG), and hence FG generates current in higher (in the order of MHz) frequency. For a moment, at their relaxation times, some of mdmspah relax and go back to lower energy level. As long as mdmspah is in relaxation condition, mdmspah radiates magnetic flux. This magnetic flux is received by RC. Output of RC gives induction voltage, which is termed NMR signals. This NMR signal is connected to a filter (for signals less than 20 Hz) and an amplifier (amplifying signals about 500 times). Finally, after the NMR signal is filtered and amplified, this signal is shown on the screen of oscilloscope digital storage. The blood flowing model in an arm could be seen in FIGURE 1.b.

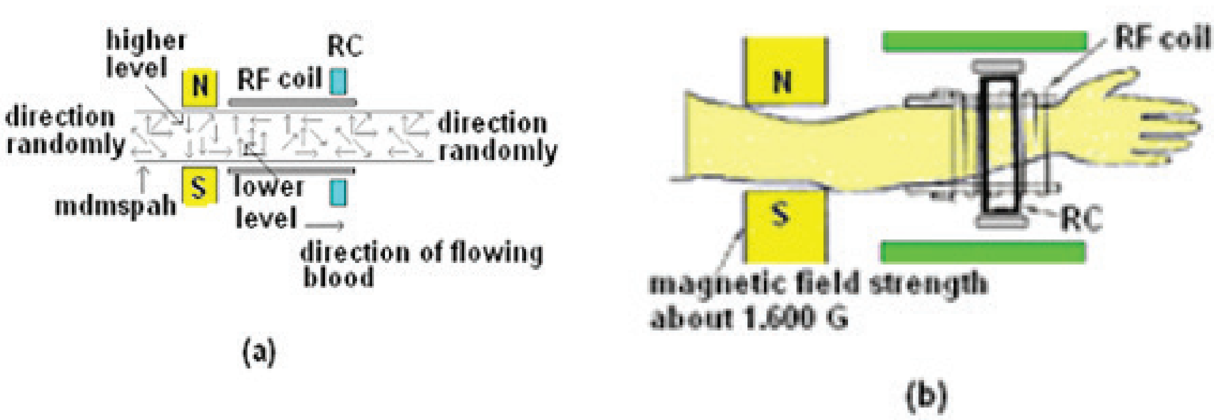

FIGURE 1. (a) The flowing model of mdmspah inside blood, (b) the flowing model of mdmspah in an arm.

The NMR signal is received from blood flow in arteries of an arm (FIGURE 1.b). However, other signals which look like NMR signals probably disturb that signal. These other signals (termed as background signals) are probably different from NMR signal in terms of resonance frequency. The source of background signal is probably ionic gas. According to kinetic theory, all atoms or molecules vibrate, rotate, and translate. If the temperature of the location is T (kelvin), the Stefan – Boltzmann constant is k, and the degree of freedom (f) is 7, the kinetic energy is $E = \frac{7}{2}kT$. If the molecules move at a speed of v, and the density of the molecules is, the pressure is $P = \frac{1}{2}\rho v^2$. This means that these ionic gases move inside the gap between N and S of permanent magnetic poles as well as inside RF coil.

The present experiment used some equipment, including home-made equipment. The equipment (shown in FIGURE 2a) was teslameter and permanent magnet (1,300 up to 1,800 gauss). Other equipment was oscilloscope, FG, amplifier including the filter, RF coil, and RC (FIGURE 2b). The amplifier – filter and the coils (RF and RC) were home-made equipment. The room temperature was measured by placing 2 thermometers at a vertical position on static. The experiment of monitoring blood pressure of a sample is shown in FIGURE 2b.

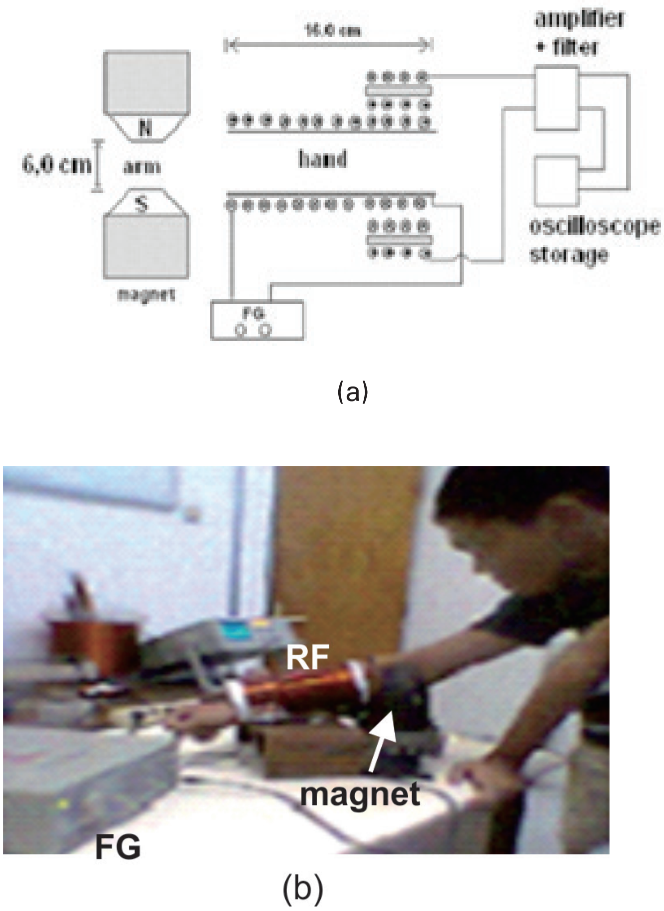

FIGURE 2. (a) The experimental set up (b) experimental testing for a sample.

The experiment was completed by putting data quantity of magnetic field as a function of some positions around the permanent magnet (FIGURE 3a, b). The magnetic distribution was put along N – S poles and perpendicular from that axis. RF coil was empty. The position of RF coil was varied in the distance from permanent magnet. Subsequently, the signal (similar to NMR signals) was seen on the oscilloscope screen and saved in a flash disc. The data of background signals were put at resonance frequency as a function of room temperature.

RESULTS

The data of the present study are the distribution of magnetic field strength (B) as a function of position and the frequency of background signals as a function of room temperature, the effect of room temperature to the background signals, and NMR signals for a sample testing. The magnetic distribution along N – S poles axis is presented in FIGURE 3a. The other one, the distribution in perpendicular direction to that axis (N – S) poles is shown in FIGURE 3b. B on the right and on the left places from those poles can be seen in FIGURE 4. In addition, the frequency of background signal at 22 ± 1°C is shown in FIGURE 5.

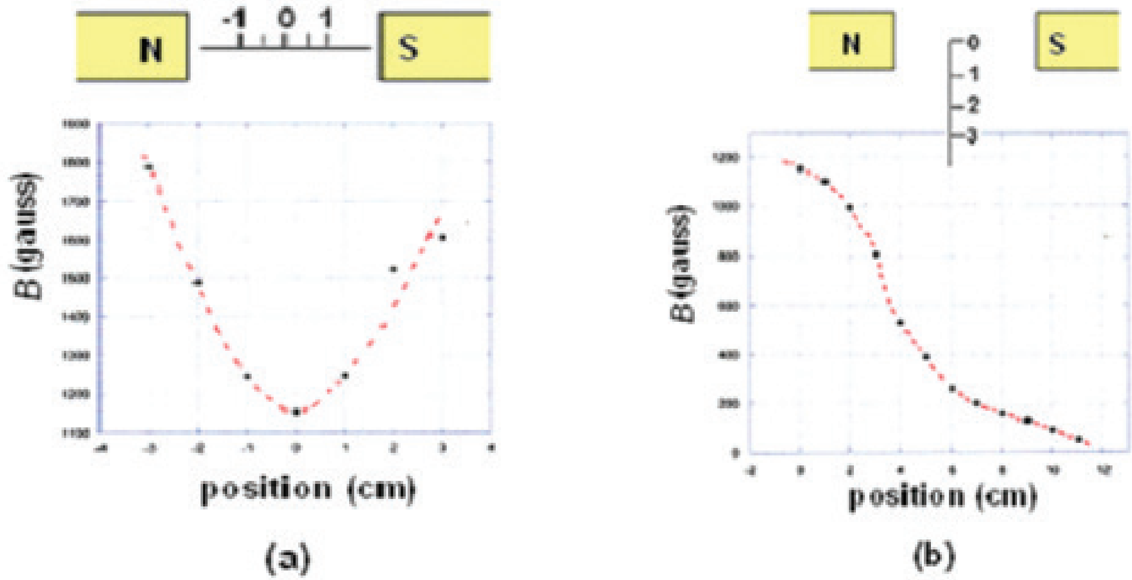

FIGURE 3.The distribution of magnetic field strength: (a) along N–S pole axis, (b) rectangular to N – S pole axis.

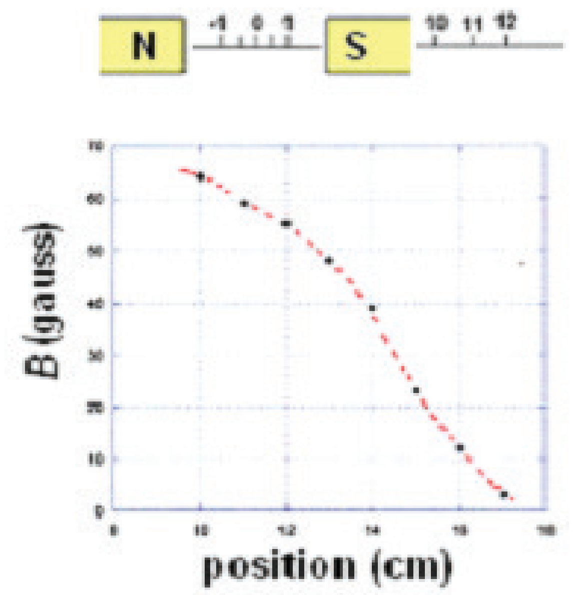

FIGURE 4. The distribution of magnetic field strength on right side place from S pole.

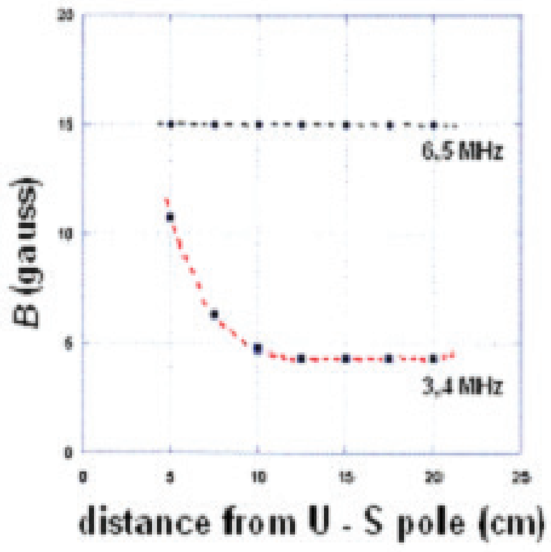

FIGURE 5. Resonance frequency of B background signal.

DISCUSSION

It can be seen from the data (FIGURES 3 and 4) that the distribution of B along N – S poles is not homogenous. However, the magnetic field in inhomogeneity could be erased by placing the sample as artery on constant position. On the other hand, B is going down sharply for more distant from the pole gap position. This means that the distribution of B from the permanent magnet does not disturb other equipment such as oscilloscope or FG. FIGURE 5 shows that the frequency of background signal is 3.4 MHz and 6.5 MHz. The frequency of this signal is very much different from NMR signal of mdmspah by flowing blood in arteries. On the other hand, resonance frequency of background signal is almost independent from room temperature (FIGURE 6). Finally, the NMR signal (for blood pressure monitoring system) is not disturbed by background signal and also it is not sensitive to room temperature. An example of NMR signal from a sample testing can be seen in FIGURE 7. The voltage of NMR signal is consistent with systole (maximum voltage) – diastole (minimum voltage) when blood was flowing inside arteries in sampled arms. The frequency of NMR signal is 4.7 MHz. This value is consistent with larmor frequency of mdmspah.

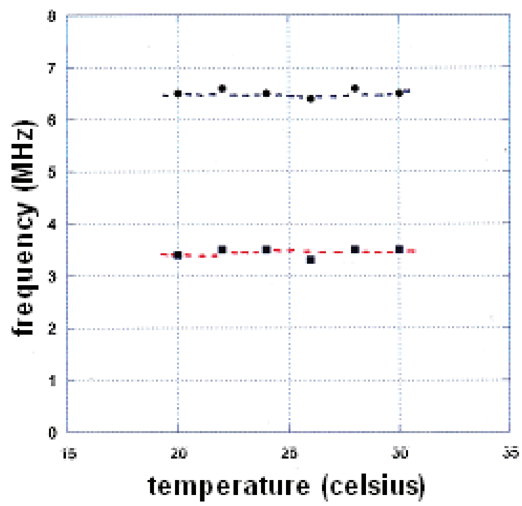

FIGURE 6. The background signal is constant at constant RF coil position, at room temperature of 20 to 30°C.

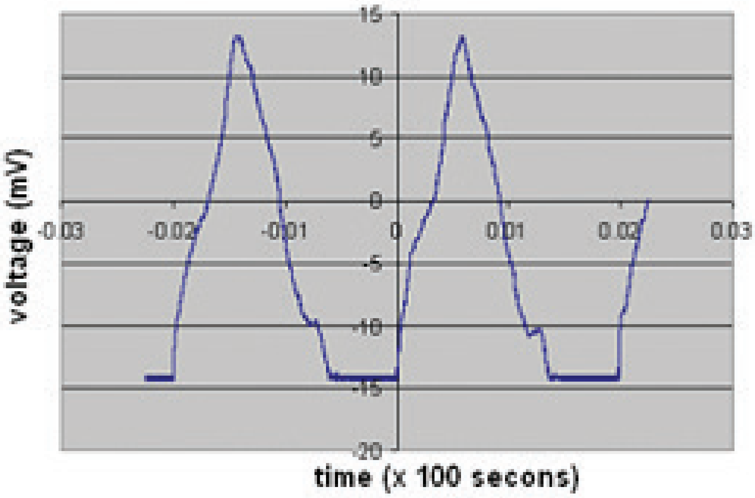

FIGURE 7. NMR signal (in mV) from a sample is similar to systole/diastole (110/70 mmHg).

CONCLUSION

It can be concluded that, first, the distribution of magnetic field strength for around 20 cm from the poles of permanent magnet is too small. This means that this magnet does not disturb other electronic equipment. Background signals could be found but these signals are not sensitive to coordinate and room temperature. Second, it could be measured that the background signal frequency is 3.4 and 6.5 MHz. It means that the background signal does not disturb NMR signal (about 4.7 MHz) which is produced by mdmspah from flowing blood in the arm of the sample artery. Third, the similarity of NMR signal (in mV) to blood pressure (as measured in mmHg using sphygmomanometer) from a sampled testing could be seen by an oscilloscope. It is expected that this research could be developed for bigger magnetic field strength (more than 7,000 gauss) on maximal sensitivity of NMR signal. From the next step of research, the equipment (NMR system) could be applied to measure blood pressure on time for some condition of samples.

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