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BLOOD PRESSURE MONITORING SYSTEM USING NMR METHOD

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Abstract:-
A new blood pressure monitoring system on human arm artery using NMR method has been constructed. The system is a non-invasive blood pressure measurement system which is as sphygmomanometer, but more accurate since it uses the blood pressure pulse wave as in the catheter method. The system has been constructed by varying the wire winding number in the RF coils (varied from 100 to 500 turns) and the cross section area of the RC (varied from 50 to 125 cm^2). We found that the biggest NMR signal is attained when the RF coil winding number is 500 turns and the RC cross section is 50 cm^2. Data from five subjects give NMR signal (E) in mV for different blood pressure (P) measured by sphygmomanometer in mmHg. We found a linear relation between E and P, but with two different slopes. On small P (from 60 up to 90 mmHg) the slope of E versus P is (101±6) mV/mmHg, while on large P (from 100 up to 130 mmHg) the slope is (203 ± 4) mV/mmHg.

Keywords:- *Blood pressure measurement, NMR method*

I. INTRODUCTION

Nuclear Magnetic Resonance (NMR) has been widely used for analyzing magnetic materials, from which some magnetic related parameters can be known, such as the spin-spin relaxation time (T_1) and spin-lattice relaxation time (T_2), the Lande constant, the chemical shift, and also the spin concentration of proton magnetic dipole moment (pmdm) in hydrogen atom **[1, 2]**. In its latest technological development, NMR could be used to scan the image of inner soft human organ **[3]**. This technology is based on the fact that 70% of human soft organ is water, where the dominant atom is hydrogen. Since water contains many hydrogen atoms, then water molecule has a big concentration of pmdm. This technology is called the Magnetic Resonance Imaging (MRI) **[4, 5]**. MRI gives only qualitatively discription of the object, since the image of the object could be seen, but no qualitative value being produced **[6, 7]**. While measuring blood pressure should give a quantitative description on certain body function, i.e. the blood pressure. So far there is no application of NMR technology on the blood pressure measurement.

There are two famous techniques in blood pressure monitoring system that have been known. Those techniques are the sphygmomanometer method and the catheter method. The sphygmomanometer method uses the turbulence of blood flow in the artery of human arm. This technique is simple and non-invasive (without disturbing body organ), so it is saver and cheaper than the catheter method. But unfortunately, this method is less precise. Sphygmomanometer measurement is less precise because it contains three source of errors: pressure cuff, manometer, and the stetoscope. Nevertheless this method gives reliable result for monitoring the blood pressure of a healthy subject **[8.9]**.

The catheter technique is based on the blood pressure wave inside the artery of a subject. It is not simple because the device is small in dimension and thus using advance technology, and therefore it is expensive. It is also invasive (the mechanism is disturbing the body organ of the subject) thus this method is not save. But the blood pressure measurement using catheter method is more precise than the sphygmomanometer method. On this catheter method, the error source comes from the pressure given on the artery axis. Catheter method is good to be used on patient in critical condition **[10]**. It would be nice if we can have a new technique for blood pressure measurement that is non-invasive, more precise than the sphygmomanometer but affordable. In this paper we describe our research to build a new blood pressure measurement system based on NMR principle. This NMR method is non-invasive, so it will be as save as sphygmomanometer. But it is based on the blood pressure wave, as in the catheter method. We claim that this technique could give more advantages than the usual two methods above. It is a save, non-invasive, affordable and precise method for blood pressure measurement **[11, 12]**.

The other advantage of this technique is that the blood pressure value of subject could be translated directly into an induction voltage (mV) value, which can be read on a display, printed on a printer, and also saved on a computer.

II. THEORY, METHODOLOGY, RESULT AND DISCUSSION

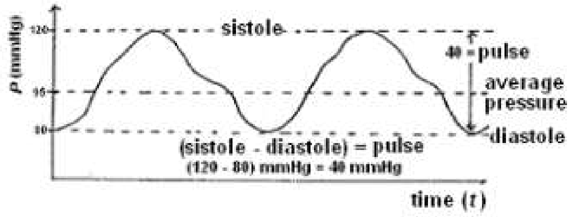
2.1 Theory

The theory is based by two kind of information: first (blood circulation and their pressure) dan second (NMR).

First, there is two kind of human blood circulation: the big loop (runs from heart – all organs – heart) and small loop (runs from heart – lung – heart). Blood can be circulated (via artery and vena) to all parts of human body by the action of heart pumping. This process consist of contraction and relaxation of the heart muscles. Blood can be circulated (in an artery and vena) only in a forward direction because inside the heart and the vena there are some cleps that prevent the blood to circulate in the reverse direction. When the heart is contracting, the blood pressure is at its biggest value, and it is called sistole. While when the heart is relaxing, the blood pressure is at its lowest value, and it is called diastole. The graph of sistole – diastole as a function of time on the big and small loop is shown in Figure 1.

From the figure, one can read some names given for the blood pressure graph. Blood pressure pulse (P_p) value is defined by sistole substracted by diastole. The average blood pressure value (P) is the blood pressure average as a function of time

$$\overline{P} = \frac{1}{T}\int_0^T P(t)dt$$ **[13, 14]**



(a)

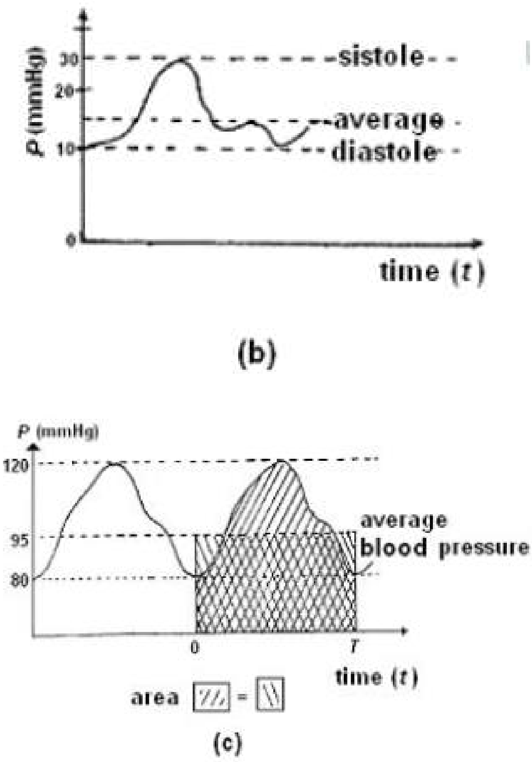


Figure 1 Blood pressure on: (a) big loop, (b) small loop, and also (c) the method to find an average Blood pressure.

Blood flows along the artery and vena is depent on its flowrate. The flowrate character is depent on the character of the heart (contraction and relaxation), and the blood pressure (Figure 2) **[15,16]**.

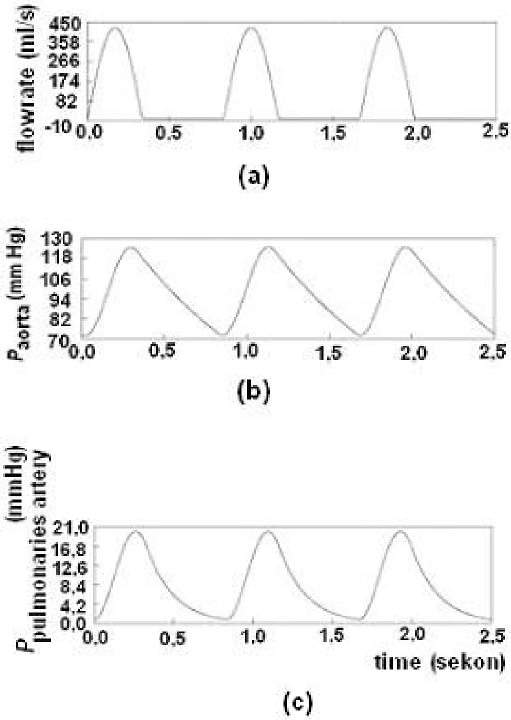


Figure 2 (a) Flowrate as a function of time, and (b) Aorta blood pressure as a function of time, (c) pulmonaris artery blood pressure as a function of time.

The blood on the big loop flows through some vital organs of human body. This means, the blood pressure information on the big loop and their dynamics on a person can give valuable information about the subject health condition. In our research we use the big loop blood pressure, in particular the blood pressure measured in the subject arm artery (artery branchialis). We choose that artery because its diameter is big enough (about 0.5 cm) and it is not too far from the heart. This means, inside the artery, the blood flow speed is almost homogeneus and the flow is laminer. So, that the blood flow is consisten to the continuity equation and the Poiseuille equation. If the artery radius is r, the speed of blood flow inside the artery is v, and their flowrate is Q, then the continuity equation can be written as $Q = \frac{\pi}{4} r^2 v$. While for 4 Poisseuille equation, if the blood viscosity isη, the length of the artery is L, and the pressure difference between the two ends of L is ΔP, then the Poisseuille equation can be witten as $Q = \frac{8r^2 \Delta P}{\eta L}$

Second, NMR process depends on the energy transition of the spin magnetic dipole moment of protons in hydrogen atom. The pmdm is a property of a proton in the hydrogen atom. While in the water molecule the hydrogen atom is dominant, and more than 90% of blood is water. Thus blood contain many pmdm. Blood flows (in the arm artery of the subject) from left to right (Figure 3a). This process is similar to the flowing of fluid inside a pipe (Figure 3b). Initially, pmdm ($\vec{\mu}$) is randomly oriented and flows from left to right. After the $\vec{\mu}$ entering the magnetic field area with a magnetic field strength B_o, the pmdm gain a potensial energy ΔE given by

$$\Delta E = -\vec{\mu} \cdot \vec{B}_o \qquad (1)$$

Some of pmdm are in the lower energy state $(\Delta E = -\mu B_o)$, meaning that μ is the same direction as B_o. Since $\vec{\mu}$ (inside the blood) flows from left to right, then $\vec{\mu}$ received electromagnetic radiation from the function generator (FG) at frequency v_O. If the v_o value is equal to the Larmor frequency, on gyromagnetic ratioγ, then there will be a resonance, whose frequency relation is given by

$$v_o = \gamma B_o \qquad (2)$$

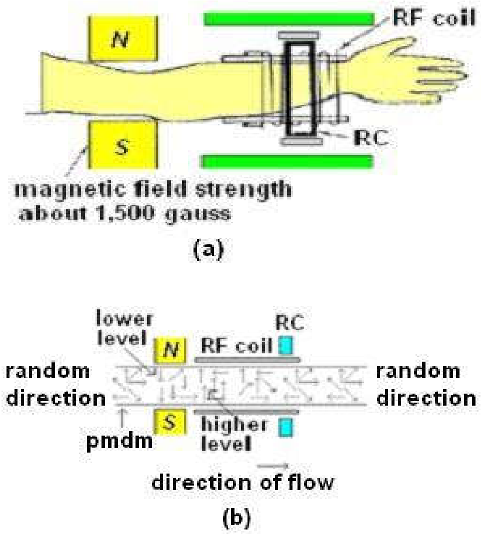


Figure 3 (a) Arm of a subject is placed between two magnetic poles, and (b) the dynamic model of pmdm inside the blood flow.

Due to exitation, some of $\vec{\mu}$ are populating the upper level, and thus the population at lower level (n_1) is different to the upper one (n_2). If the blood temperature is T and Stefan Boltzman is k, then the relation between n_2 to n_1 can be approximated as:

$$\frac{n_2}{n_1} = 1 - \frac{\Delta E}{kT} \qquad (3)$$

From this equation, one can be introduce a new variable, called the spin excess$(\Delta n = n_2 - n_1)$. So, the relation between Δn, B_o, and T, with Plank constant h can be written as **[18]**

$$\Delta n = \frac{\gamma h B_o}{2\pi k T} \qquad (4)$$

From equation (4) we found that the population of $\vec{\mu}$ will increase if B_o is being increased, or when T is being decreased. In this experiment, the subject blood temperature cannot be adjusted, then one can only increase Δn by increasing B_o (the increament is linear to v_o). If the magnetic field strength of the permanent magnet is 10,000 gauss, then $T1$ = 0.8 s and T_2 = 0.2s. The relaxation of $\vec{\mu}$ is due the magnetic flux change$d\phi_B$. If the magnetic flux change is $d\phi_B$in a time duration of dt, then the induction voltage (called NMR signal) ε could be written as:

$$\varepsilon = -\frac{d\phi_B}{dt} \qquad (5)$$

This induction is received by the RC. In reallity, this signal is too small, so one must use an amplifier (amplified 500 times) and filtered (filtered under 20 Hz). The NMR signal can be seen on a digital storage oscilloscope display (in mV).

2.2 Methodology

The setup of the NMR blood prssure monitoring system is the following. The following equipments are used: a permanent magnet (B_o= [1.500□ 300] gauss), an RF coil and RC, filter and amplifier, FG and a digital storage oscilloscope (type ADS 1102 CAL, 100 MHz, 1 Gsa/s). The RF coil diameter is 11.5 □ 0.5 cm. This RF coil diameter is choosen just to make sure that the arm of a subject can fit inside it. The blood flowing inside an arm artery with the speed around 0.5 m/s, and the relaxation of pmdm is T_2 (= 0.2 s). During that relaxation time, the blood in the arm artery has flowed for a distance of about 10 cm. Thus we choose the length of the RF coil to be 16.0□ 0.5 cm. RC coil (on a serial contruction) have been placed next to the RF coil. We use 500 turns on RF coil, and 40 turns on RC. The RC cross section is 50 cm^2. The wire diameter in both the RF coil and RC coil is 1.2 mm. The cross section and the winding number of the RF coil and RC above is the result from saveral trial of different cross section and winding number that can give the best NMR signal (500 turns on RF coil and 50 cm^2 on RC). The system is then run and tested for several subjects. The NMR signal (read on the oscilloscop display, in mV) of several subject is then compared to the blood pressure value of the subject from sphygmomanometer (in mmHg).

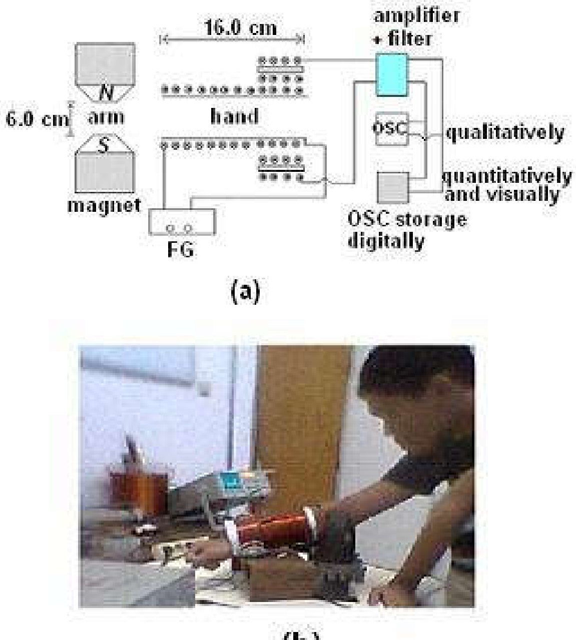


Figure 4 (a) The setup of the NMR blood pressure monitoring system, and (b) the set up operating With a subject.

We believes that the NMR signal depends on the blood pressure value of the subject. The relation dependency of the NMR signal and the blood pressure is checked in four steps. First, the RC locations are being varied and we found that the RC position next to the RF coil gives maximal NMR signal. Second, the FG frequency at B_o (1,500 ± 300) gauss is consistent to the larmor frequency (4.7 ±0.3) MHz. Third, the NMR signal of a subject is checked and compared to an NMR signal from blood at rest. Fourth, the blood pressure of the subject are checked twice by sphygmomanometer, before and after the operation of the NMR signal.

2.3 Result and Discussion

We use a child and several boys as the subjects. Figure 5 a,b shows two signal character as function of time. The NMR signal on sistole/diastole for a child is about 13/9 mV, and for a boys is 18/9 mV.

Data from 5 subjecs are taken, and we plot the NMR signal (E, in mV) versus the blood pressure value measured using sphygmomanometer (P, in mmHg). The data give a linear fungction (Figure 6) but with two different slope values for two different region of P. The two different slope values devide blood pressure value into two region on small P (60 up to 90 mmHg) and large P (100 up to 130 mmHg). The relation can be written as:

$$E = a + bP \qquad (6)$$

In the first region of P (60 – 90 mmHg), a is is a_1 = - (0.03 ±0.44) mV and b is b_1 = (101 ±6) x10^{-2} mV/mmHg, while in the second region of P (100 – 130 mmHg), a is a_2 = -(9.8 ± 0.4) mV and b is b_2 = (203 ± 4)10^{-2} mV/mmHg.

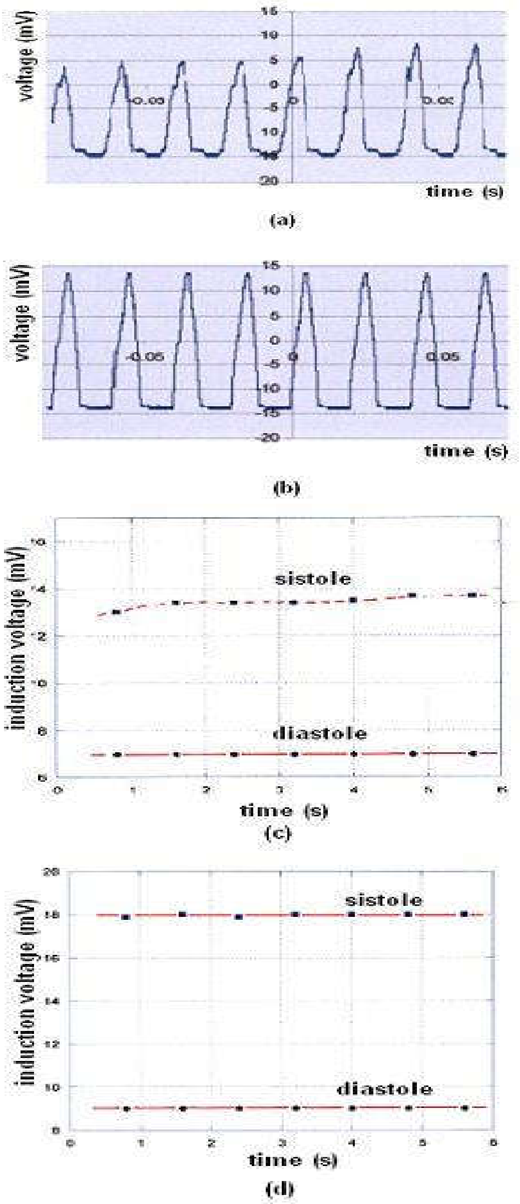


Figure 5 NMR signal from a subject: (a) child, (b) boys, and the sistole/diastole as function of time for: (c) a child, and (d) a boys.

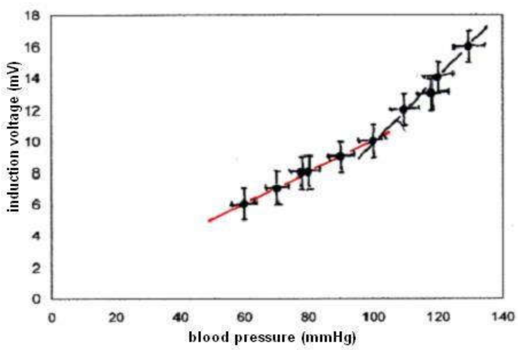


Figure 6 The NMR signal (in mV) versus the blood pressure (in mmHg) measured by sphygmomanometer.

The two different slope in the relation between the NMR signal and the blood pressure can be explained as follows. When the P is small then the blood speed v is also small, thus the relaxation of pmdm (at a distance of x_d, in the front side of RC, see Figure 7a) have finished with a duration T_2. While if P is bigger, then the blood speed v is faster, thus the relation of pmdm (with a duration of T_2) is at a distance x_s in the front of RC (Figure 7b). Certainly, x_s is smaller than x_d. This means the magnetic flux is changing faster, on a bigger P. The bigger the P the smaller is the x_s. While smaller x_s will give bigger NMR voltage induction.

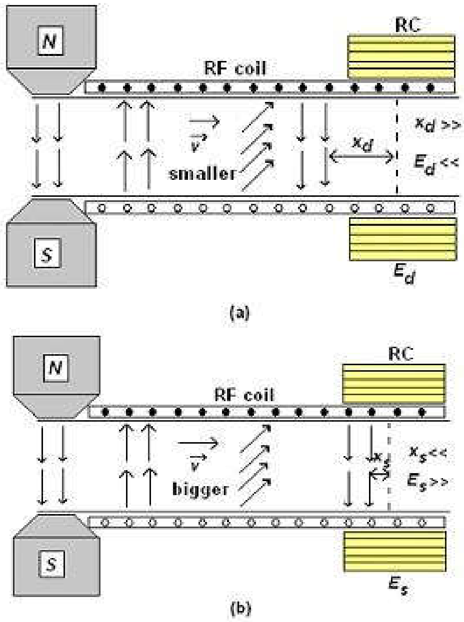


Figure 7 the flowing speed of blood is proportional to the value of the blood pressure. The slope on Small pressure is not as large as the case in a big pressure.

III. CONCLUSION AND SUGESTION

The blood pressure monitoring system using NMR method has been made. This system uses a permanent magnet of (1,500 $\pm$ 300) gauss, an RF coil with a diameter of [11.5 $\pm$ 0.5] cm, and a length of [16.0 $\pm$ 0.5] cm, with 500 turns of wire whose diameter is 1.2 mm, an RC with a crossection of 50 cm^2 with 40 turns of wire whose diameter is 1.2 mm, and a FG set with a frequency set at (4.7 $\pm$ 0.3) MHz. From 5 subject testing, we got a linear relation between the NMR voltage signal (in mV) versus the blood pressure measured by sphygmomanometer (in mmHg), but with two different 2 slopes, for small *P* and big *P*. For small P the slope is (101 $\pm$ 6) x10^{-2} mV/mmHg, while for big Up the slope is (203 $\pm$ 4) mV/mmHg.

In the future the research could be perfected by using a larger magnetic field, increasing the diameter of the arm insertion, and increasing the amplification of the NMR signal. Since increasing the pmdm population will increase the NMR signal, and the system will be more sensitive to the blood pressure value.

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