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Improvement of the Matching Speed of AIMS for Development of an Automatic Totally Tuning System for Hyperthermia Treatment Using a Resonant Cavity Applicator

Y. Shindo, K. Kato, K.Tsuchiya, T. Hirashima, M. Suzuki

Abstract— **In this paper, we discuss the improvement of the speed of AIMS (Automatic Impedance Matching System) to automatically make impedance matching for a re-entrant resonant cavity applicator for non-invasive deep brain tumors hyperthermia treatments. We have already discussed the effectiveness of the heating method using the AIMS, with experiments of heating agar phantoms. However, the operating time of AIMS was about 30 minutes. To develop the ATT System (Automatic Totally Tuning System) including the automatic frequency tuning system, we must improve this problem. Because, when using the ATTS, the AIMS is used repeatedly to find the resonant frequency.**

In order to improve the speed of impedance matching, we developed the new automatic impedance matching system program (AIMS2). In AIMS, the stepping motors were connected to the impedance matching unit's dials. These dials were turned to reduce the reflected power. AIMS consists of two phases: all range searching and detailed searching. We focused on the three factors affecting the operating speed and improved them. The first factor is the interval put between the turning of the motors and AD converter. The second factor is how the steps of the motor when operating all range searching. The third factor is the starting position of the motor when detail searching.

We developed the simple ATT System (ATT-β) based on the AIMS2.

To evaluate the developed AIMS2 and ATT- β, experiments with an agar phantom were performed. From these results, we found that the operating time of the AIMS2 is about 4 minutes, which was approximately 12% of AIMS. From ATT- β results, it was shown that it is possible to tune frequency and automatically match impedance with the program based on the AIMS2.

I. INTRODUCTION

HYPERTHERMIA treatment is based on the clinical fact that a tumor is weaker than normal tissue under the temperature of 43℃ and can be killed by heating for increments of approximately thirty minutes of heating. We proposed a non-invasive heating method using the re-entrant type resonant cavity applicator for deep brain tumors [1], [2].

With this heating method, to generate heating power in the cavity, it is necessary to make impedance matching and tune the resonant frequency. In the early prototype heating system, both were manually performed. However, it was difficult to make impedance matching and tune the frequency in high frequency electromagnetic heating.

Y.Shindo, K.Kato, K.Tsuchiya, T.Hirashima and M.Suzuki are with the Department of Mechanical Engineering Informatics, Meiji University, Kawasaki, Japan E-mail: yshindo@isc.meiji.ac.jp

We have developed an automatic impedance matching system (AIMS). We have already discussed the effectiveness of the heating method using the AIMS, with experiments of heating agar phantoms [3].

However, this system was only able to make impedance matching, and it needed a lot of time about 30 minutes at a time. When tuning the frequency, one of the criteria is the impedance matching point of the input side of each frequency. So, in order to apply AIMS to the automatic tuning of the frequency system, it is necessary to improve the matching speed of AIMS.

To overcome this problem, we have developed a new automatic impedance matching system (AIMS2). To present the possibility of applying the automatic tuning of the frequency system, we developed the simply automatic totally tuning system (ATT-β).

In this paper, we propose a new matching system which improved operating speed.

First, we improved the interval time between the rotations of stepping motor and AD converter to measure the reflected power, and the steps of the motor when all range searching and the starting position of detail searching. From these improvements, we developed AIMS2 to be faster than AIMS by about 26 minutes.

Second, we developed the ATT-β based on the AIMS2. Experimental results of heating agar phantoms using ATT-β will be discussed. Finally, from these results, it is shown that the developed AIMS2 can automatically adjust the impedance faster and it is possible to apply to automatic totally tuning system included tuning the frequency.

II. METHODS

Fig. 1 shows an illustration of AIMS. In Fig. 1, a human head is placed in the center of the inner electrodes and heated by electromagnetic fields inside the cavity without touching the body to the applicator. The impedance matching unit is connected to the cavity and heating power is supplied by the high frequency amplifier. In this system, the reflected power generated is fed back to the computer with the AD converter and the motor drive unit connected with the impedance matching unit is automatically controlled to match the impedances of input and output.

Fig. 2 shows the flow chart of AIMS. This system consists of two phases. First, to grasp the whole tendency of reflected power change, the "All range searching" is started.

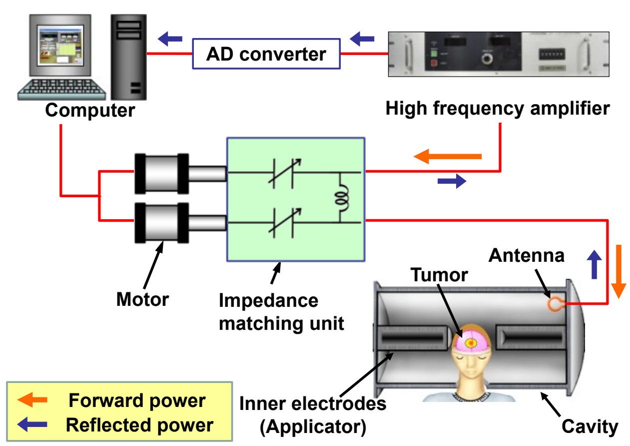

Fig. 1. Illustration of AIMS.

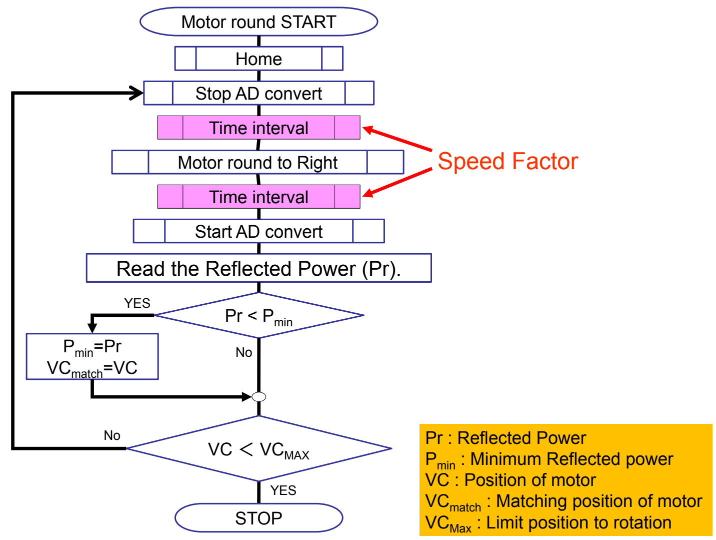

Fig. 3. Flow chart of motor drive.

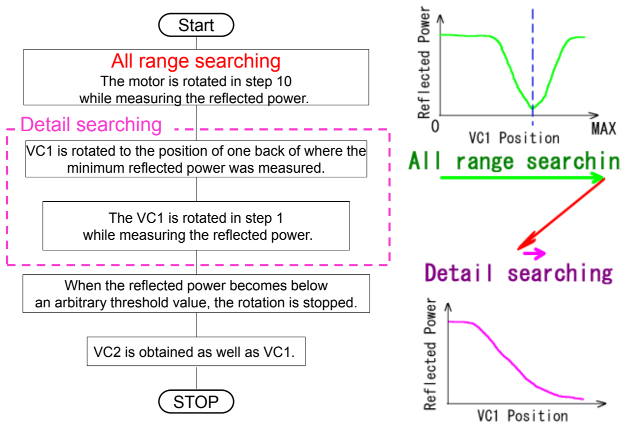

Fig. 2. Flow chart of AIMS.

In this routine, the motor is rotated to the full range of the VC1 by 10 steps. After "All range searching", VC1 is set to around the point of minimum reflected power. In addition, one rotation direction of initial position is made. Because the backlash is generated between the motor and impedance matching unit. From this position, the "Detailed searching" was started. Furthermore, in order to find the minimum value of reflected power with more accuracy, VC1 is rotated by 1-step. When the reflected power decreases below an arbitrary threshold value, rotation is stopped. VC2 is also obtained as well as VC1.

III. Results And Discussion

A. Developed AIMS2

To improve the operating speed of AIMS, we focused on the three factors. We carried out experiments with the developed system. First, the interval time was improved.

Fig. 3 shows the flow chart of subroutine of motor rotation to AD converter. In this flow chart, time intervals were put between the turn of the motors and AD converters. If we removed this interval, we could not repeat the routine accurately because of signal delay. In AIMS, the interval time is set to 100 ms.

TABLE I
Interval Changed Results

	Interval [ms]	Operating time [s]	Ratio
(a)	100	1700	100 %
(b)	50	630	35%
(c)	10	Cannot work	

First, we tested AIMS with time intervals of 100, 50, 10 ms. Results were shown in Table I. In the results, when the interval is set to 10 ms, AIMS cannot normally operate. However, when the interval is set to 50 ms, the operating time decreases approximately 65% of the original. From these results the interval was set to 50 ms in AIMS2.

Second, we improved the all range searching step, which is the step of the motor to operate all range searching. This step (All range step) is set to 10 steps in AIMS. In the experiment, "All range step" was set to 110 from 10 steps, and the interval was set to 50 ms constantly.

Table II shows the results of the operating time when changing the all range step. In this table, "Matching" means the accuracy of discovery of matching point. "Good" means that the AIMS can find the sudden change of reflected power at all range searching, "Not Good" means that the changing of reflected power is gradually than "Good" value even get matching. In this result, when all range step is set to 40 steps, the operating time decreases approximately 53 % of the result of 10 steps. Even change all range step more, the increase of the operating time becomes gradually. The progress of the operating time in each all range step is shown in Fig. 4. Here, the affixing character "A" means that the time of all range searching finished, "D" means that the time of detail searching finished. In this figure, the slope from start to VC1(A) is dropped as the all range step increased. From these results, the all range step is set to 40 steps in AIMS2.

TABLE II
ALL RANGE STEP CHANGED RESULTS

	All range step	Operating time [s]	Ratio	Matching
(a)	10	633	100 %	Good
(b)	20	436	69 %	Good
(c)	30	311	49 %	Good
(d)	40	298	47 %	Good
(e)	50	276	43 %	Good
(f)	60	314	49 %	Good
(g)	100	235	37 %	Not Good
(h)	110	251	40 %	Not Good

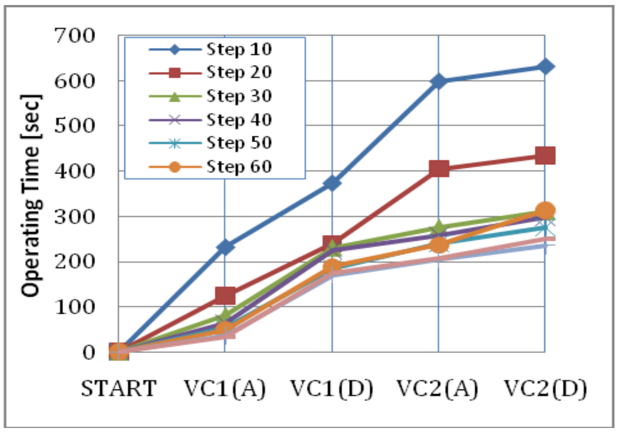

Fig. 4. Progress of operating time.
(All range step changed)

Finally, the starting position of detail searching was improved. In AIMS, the starting position of detail searching was one rotation far from the minimum reflected power was given in all range searching. This quantity of back forward is called BR (Back-Rotation). If the BR is 0.6, it means that the position of starting all range searching is 0.6 rotations far from the minimum reflected power position in all range searching. In experiment, BR is set to 1.0, 0.8, 0.6, 0.5, 0.4, 0.3 steps, and all range step is set to 40 steps, and the interval was set to 50 ms constantly.

Table III shows the results of experiments with changing the BR. Each result was good at matching. And operating time ratio decreases as BR becomes smaller.

The progress of operating time is shown in Fig. 5. The gradation from VC1(A) to VC1(D) decreased as BR was changed. However, the gradient from VC2(A) to VC2(D) was not changed. Because the matching point of VC2 was near the initial position. From these results, BR was set to 0.3 in AIMS2.

From these improvements, the fast automatic impedance matching system AIMS2 was developed. In AIMS2, the operating time was approximately 230 s operating time was approximately 230 s which is about 12% of that of AIMS.

TABLE III
BR CHANGED RESULTS

	BR [rev.]	Operating time [s]	Ratio
(A)	1.0	298	100 %
(B)	0.8	281	94.3 %
(C)	0.6	244	81.9 %
(D)	0.5	252	84.6 %
(E)	0.4	231	77.5 %
(F)	0.3	221	74.2 %

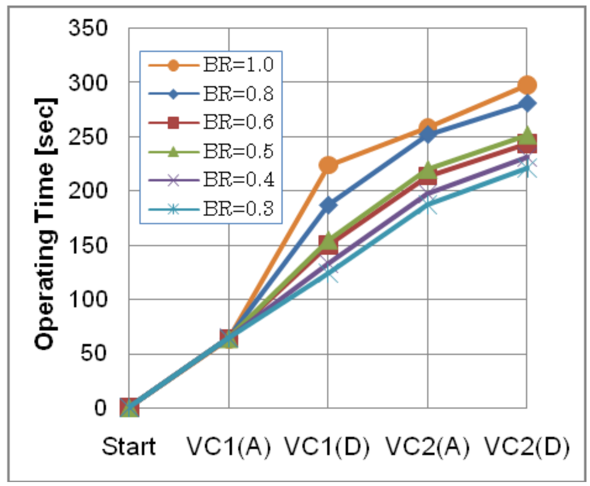

Fig. 5. Progress of operating time.
(BR changed)

B. *Developed ATT-β*

We developed the simple automatic totally tuning system (ATT-β). The system included the frequency tuning based on the AIMS2 to confirm the possibility of applying the AIMS2 to the totally tuning system.

Fig. 6 shows the flow chart of ATT-β. In ATT-β, the resonant frequency estimated by FEM was used as the basis frequency (=f_0) [4]. First, to grasp the whole tendency of reflected power change, the "All range searching" was started at basis frequency and the area of detail searching was decided. The searching frequency range is that from -4 MHz of basis to +10 MHz. It was understood that the resonance frequency existed in higher frequency than the estimated results from our experiments. And the detail searching was carried out in each frequency and comparison of the distance of reflected power. The distance of reflected power (=⊿P) means the distance from maximum reflected power to minimum reflected power in each frequency. Therefore the reflected power was wasted at connection or the other part of systems not in resonant frequency. So the resonant frequency gives the biggest ⊿P, we choose the ⊿P as the factor of resonance state in this system.

Fig. 7 shows the operation form of the developed software ATT-β. The source program was written by Visual Basic.

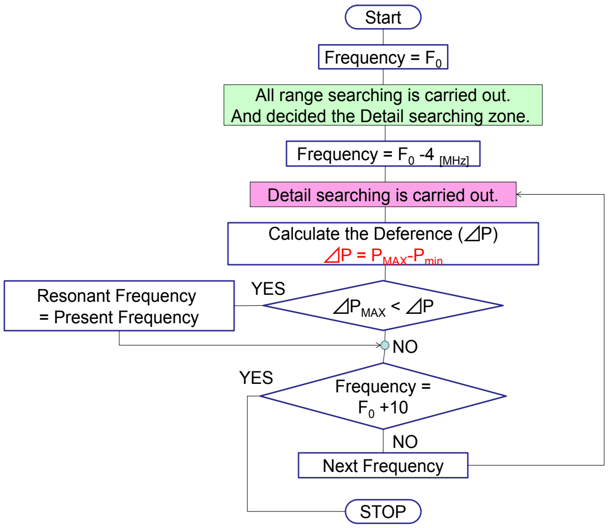

Fig. 6. Flow chart of ATT-β.

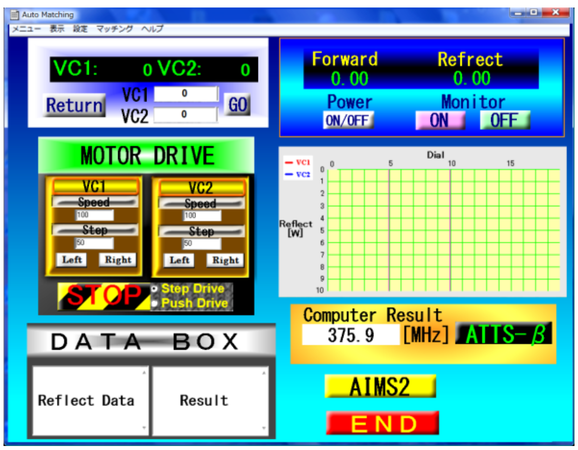

Fig. 7. Operation form of ATT-β.

When the matching operation was carried out by ATTS-β, heating power was set to 8W. After finding the resonant frequency automatically, we heated the agar phantom by 30W. The estimated frequency was 375.9 MHz as basis frequency.

Fig. 8 shows the measured data of the reflected power difference in each frequency searching by 1 MHz. In Fig. 8, the difference changed in each frequency. And the maximum difference was given at 378.9 MHz. Repeating this operation by 0.1 MHz and 0.01 MHz, as a result, the resonant frequency was 380.35 MHz. The total operating time was about 2 hours.

Fig. 9 shows the thermal image of sagittal slice of agar phantom taken by an infrared thermal camera after 60 minutes heating by the re-entrant resonant cavity at 380.35 MHz. From Fig. 9, the center of the agar phantom was heated to maximum temperature, and the temperature rise was about 5.3℃.

It was shown that the cavity is resonated at this frequency and this system is able to apply to the automatic totally tuning system.

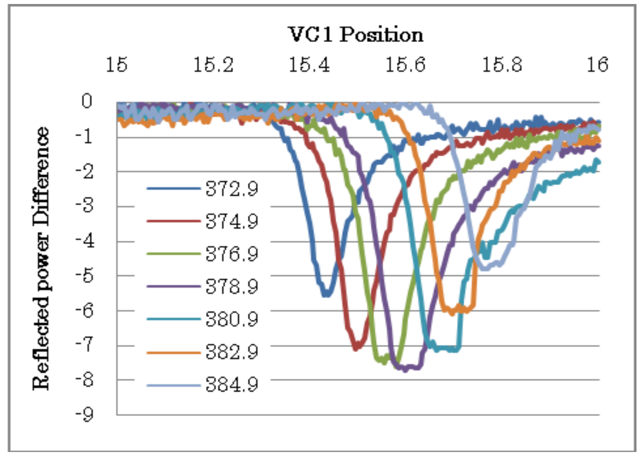

Fig. 8. Flow chart of motor rotation.

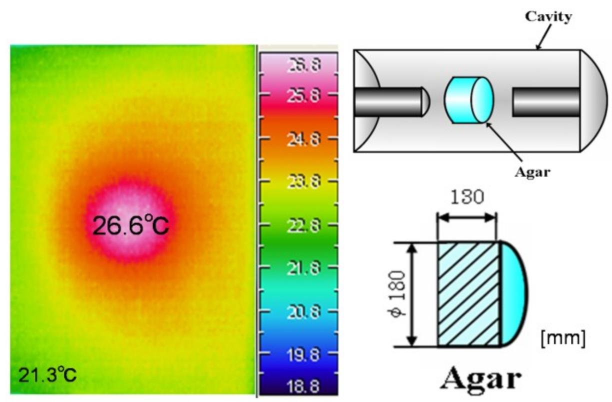

Fig. 9. Thermal Image of agar phantom.

IV. Conclusion

To develop the automatic totally tuning system that includes frequency tuning, we improved the matching speed of AIMS and developed the AIMS2. From improvement results, we found that the operating time of the AIMS2 is about 4 minutes, which is approximately 12% of AIMS.

We developed the ATT-β which is the simple ATT system based on the AIMS2. The experiments with the agar phantom were performed. From ATT-β results, it was shown that it is possible to tune frequency and to make impedance matching automatically with the program based on AIMS2.

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