A study on water content measurement of wood lumber using sound wave analysis

Hisao Fujikura* and Norimichi Kawashima**

桐蔭横浜大学医用工学部

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Abstract

We examined the effective use of wood lumber from a biomedical engineering perspective. We therefore studied how to change wood lumber from low to high quality. High quality wood refers to materials with a water content that is precisely controlled. Specifically, the proper control of water content is necessary when utilizing wood in building structures and as materials for outdoor civil engineering works.[1), 2)] The quality of wood is guaranteed by the Japan Agricultural Standard (JAS) in terms of water content and strength. In general, however, most wood lumber does not pass JAS.

Consequently, a high-precision water content measuring apparatus is necessary to precisely control water content. Water content measuring apparatuses are classified roughly into the following two types, the handy type for wood radii smaller than 50mm and the large-scale type for wood with radii larger than 50mm. In general, while the water content of wood used in building structures and as materials for outdoor civil engineering works is measured using a large-scale type apparatus, measurement is limited, showing its poor versatility.

We therefore studied a high precision and stable water content measuring apparatus using sound wave analysis. Japanese cypress and Japanese cedar were used as specimens for water content measurement. We hit one side of a rectangular wooden specimen with a spherical wooden pendulum and analyzed the sound waves at the other side of the specimen using a wavelet transform in frequency and time using a bio-sound analyzer.

We measured the frequency component of the sound waves of specimens with different water contents using the weight method. The relationship between the frequency component of the sound waves and the water content showed good correlation. The frequency of the hit sounds above 850Hz showed that the water content of the wood lumber was below 30% (high quality). Sound wave analysis can be used to measure the water content and observe the defects inside wood lumber.

Graduate school of Biomedical Engineering*, Department of clinical Engineering, Faculty of Biomedical Engineering**, Toin University of Yokohama, 1614 Kuroganecho, Aoba-ku, Yokohama, 225-8502

1. Introduction

Measures for the reduction of carbon dioxide emissions for the prevention of global warming were implemented from April, 2008. The government decided to reduce 3.9% of the overall CO2 emissions from the 6% reduction target value through forest maintenance. Similarly, each administrative division in Japan maintains forests through their own forest eco-taxes, making it necessary to use an enormous amount of wood lumber.

In general, wood lumber is said to be of low quality. Therefore, low quality materials have to be replaced with high quality ones. The quality of wood depends on the water content of the wood. If the water content of the wood can be kept to less than 30%, the wood lumber becomes high quality. High quality wood refers to materials with a water content that is precisely controlled. The quality of wood is guaranteed by the Japan Agricultural Standard (JAS). As a result, the proper control of water content is necessary in order to utilize wood in building structures and as materials for outdoor civil engineering works.

The reason why the quality of wood lumber is low is due to the fact that quality control methods (water content and strength) for wood lumber have yet to be established. Water content measuring apparatuses are classified roughly into the following two types, the handy type for wood radii smaller than 50mm and the large-scale type for wood with radii larger than 50mm. In general, while the water content of wood used in building structures and as materials for outdoor civil engineering works is measured with a large-scale type apparatus, measurement is limited, showing its poor versatility.

The water content measuring apparatuses used so far are based on electrical properties (electrical resistance, a dielectric constant, the dielectric loss of the wood), high frequency and mass measurement. [3] In respect to the measurement of electrical properties, high water content in wood is impossible to measure. In addition, temperature revision is required. Wood samples greater than 50mm thick cannot be measured using the high frequency method. Although the mass measurement method is reliable, the apparatus becomes overly large. [4),5)]

We therefore studied a high precision and stable water content measuring apparatus using sound wave analysis. Japanese cypress and Japanese cedar were used as specimens for water content measurement.

2. Experimental

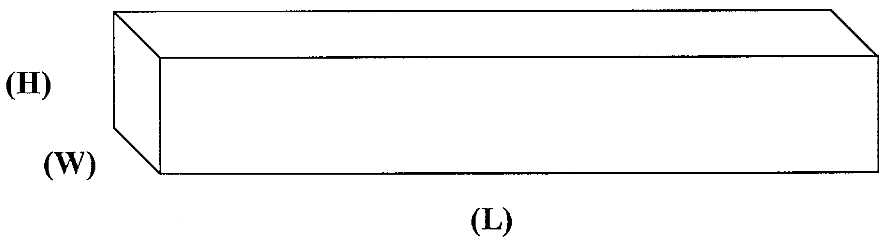
2.1 Materials

Eight Japanese cypress and nine Japanese cedar specimens without knots were used in this experiment. Fig. 1 shows the dimensions of the specimen wood cubes. Here, (H) = height (1000mm), (W) = width (100mm), (L) = length (100mm), respectively. Wood lumber that was 25 to 30 years old was used for the specimens.

Table 1 shows the water content measured using different methods in the equilibrium moisture content region, levels below the fiber saturation point and levels above the fiber saturation point. The water content of three specimens of Japanese cypress and three specimens of Japanese cedar was measured in the equilibrium moisture content region (water content below 15%), below the fiber saturation point (16 to 30% water content) and above the fiber saturation point (water content above 31%). The water content was measured using the weight method.

2.2 Sound analysis using a bio-sound analyzer

Figure2 shows the experimental system using a spherical wooden pendulum and a tapping sound analyzer (a bio-sound analyzer) [6),7)] We hit one side of a



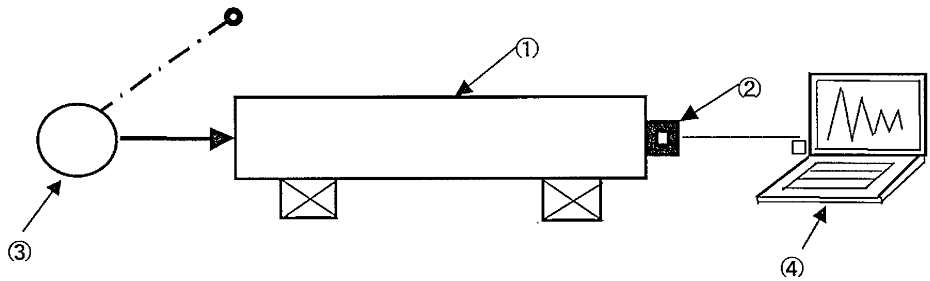
H = 100mm W = 100mm L = 100mm

Fig.1 Specimen dimension of wood cubes.

Table 1. Water content measurement using different methods in the equilibrium moisture content region, levels below the fiber saturation point and levels above the fiver saturation point.

	A - 15% Under				B-16%~30%				C-30% Over			
	A				B				C			
	No.	WM	W	HQ	No.	WM	W	HQ	No.	WM	W	HQ
Japanese cypress	A1	14%	4,10kg	13%	B1	18%	4,25kg	16%	C1	36%	4,90kg	25%
	A2	15%	4,14kg	14%	B2	22%	4,39kg	19%	C2	40%	5,04kg	28%
					B3	25%	4,50kg	22%	C3	43%	5,15kg	31%
					B4	30%	4,68kg	27%				
Number of Pieces				2				4				3
	No.	WM	W	HQ	No.	WM	W	HQ	No.	WM	W	HQ
Japanese cedar	A1	12%	3,58kg	11%	B1	20%	3,84kg	18%	C1	35%	4,32kg	25%
	A2	14%	3,65kg	12%	B2	28%	4,10kg	25%	C2	40%	4,48kg	30%
					B3	30%	4,16kg	27%	C3	48%	4,74kg	33%
									C4	50%	4,80kg	37%
Number of Pieces				2				3				4

WM : Measurement by Weight. W : Weight. HF : Measurement by High Frequency.
A : Equilibrium moisture content region.
B : Levels below the fiber saturation point.
C : Levels above the fiber saturation point.



① Wood lumber. ② Sensor
③ Pendulum of spherical wood. ④ Bio Sound Analyzer.

Fig.2 Experimental system using pendulum of spherical wood and a tapping sound analyzer.

rectangular wood specimen with a spherical wooden pendulum (diameter: 50m, weight: 60g, arc length: 200mm) and analyzed the sound waves on the other side of the specimen through a wavelet transform in frequency and time using a bio-sound analyzer.[8)-12)]

Figure3 shows the body sensor (a TA-512D acceleration sensor made by Nihon Kohden Co., Ltd.).

Figure4 shows the bio-sound analyzer made by Chuo Electronics Co., Ltd. The sound analysis was carried out three times for each specimen of Japanese cypress and Japanese cedar (at a total of 54 points).

2.3 Examination of the sound wave of the frequency spectrum using a CT scan

We examined the "tailing phenomena" in which the frequency components appear over time in the wavelet transform image. We measured the Japanese cypress specimens with and without the tailing phenomena using X-CT (Siemens SOMATOM Sensation Cardiac 64) as shown in Fig. 5.

3. Results and discussion

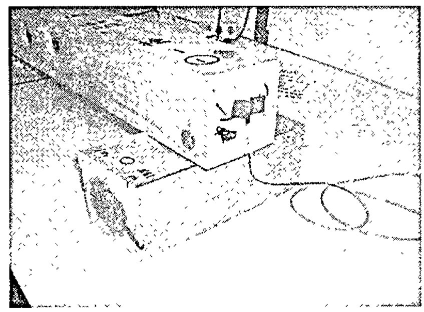


Fig.3 Body sensor (a TA-512D acceleration sensor) made by Nihon Kohden Co., Ltd.

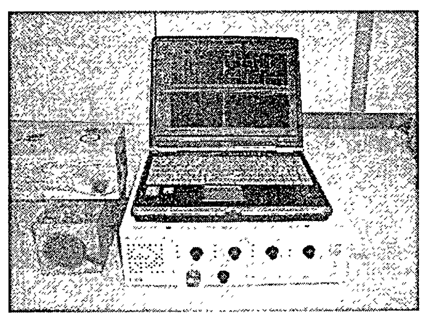


Fig.4 Bio-Sound Analyzer made by Chuo Electronics Co.,Ltd.

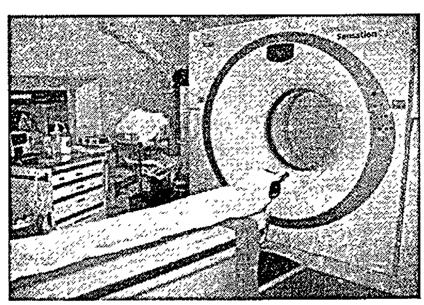


Fig.5 X- CT (Siemens SOMATOM sensation Cardiac 64).

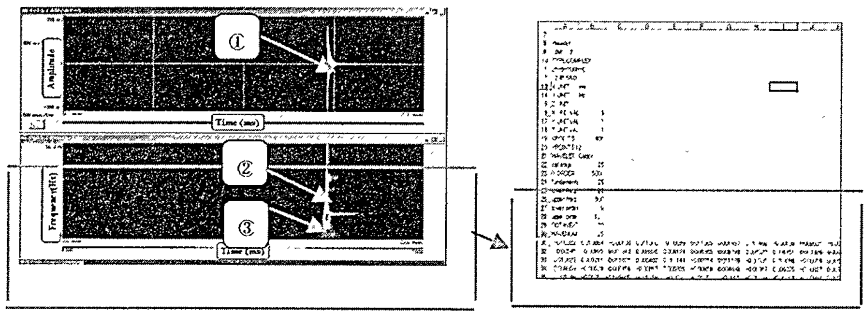


Fig.6 Power spectra and extracted data.

① Signal wave of the tapping sound.
② The frequency spectrum of the tapping sound.
③ The frequency spectrum of the tapping sound.

Table 2. Extraction data.

		Time	Frequency	Amplitude
2	1	900	428 7094	2 435846
3	2	900	443 8278	2 628768
4	3	900	459 4793	2 788341
5	4	900	475 6828	2 952184
6	5	900	492 4578	3 080072
7	6	900	509 8243	3 146499
8	7	900	527 8032	3 121346
9	8	900	546 4161	3 019247
10	9	900	565 6854	2 810271
11	10	800	585 6343	2 593831
12	11	900	606 2866	2 288708
13	12	905	414 106	2 376826
14	13	905	428 7094	2 661986
15	14	905	443 8278	2 891766
16	15	905	459 4793	3 113196
17	16	905	475 6828	3 346561
18	17	905	492 4578	3 511989
19	18	905	509 8243	3 639692
20	19	905	527 8032	3 702942
21	20	905	546 4161	3 60513
22	21	905	565 6854	3 343331
23	22	905	585 6343	3 046495
24	23	905	606 2866	2 698063
25	24	[illegible]	[illegible]	[illegible]

	Maximum	Minimum
Time	900	910
Frequency	414 106	627[illegible]73
Amplitude		3 702942

The maximum of the amplitude.

The threshold (%)	30	2 221 765
Total	34	

Recognition of the amplitude information

Recognition of the group information

The threshold | The group information

Frequency	Time Minimum	Time Maximum	Frequency Minimum	Frequency Maximum	Value
1	900	910	428 7094	428 7094	3
2	900	910	443 8278	443 8278	3
3	900	910	459 4793	459 4793	3
4	900	910	475 6828	475 6828	3
5	900	910	492 4578	492 4578	3
6	900	910	509 8243	509 8243	3
7	800	910	527 8032	527 8032	3
8	900	910	546 4161	546 4161	3
9	800	910	565 6854	565 6854	3
10	900	910	585 6343	585 6343	3
11	900	905	606 2866	606 2866	2
12	905	905	414 106	414 106	1
13	906	90C	627 6673	627 6673	1

The collected tapping sounds were analyzed through a wavelet transform[6-11] in a time dependent frequency signal. First, the wave shapes before and after 7 4000m/sec were ignored and the signal wave shapes were analyzed by a wavelet transform.18) ,19 Figure 6 shows the power spectra and extracted data. The power spectra were shown by color map. The frequency components and time 12-19) were shown in the vertical and horizontal axes, respectively.

Next, the frequency components and the unsteady signal strength were shown by color map. The correct value of the strongest spectrum in the wavelet transform image could not be obtained. As a result, we extracted the necessary data from the wavelet transform using Wave- Rover (Yugo Industry Co, Ltd.) We multiplied the maximum amplitude value by the threshold (%) and we then

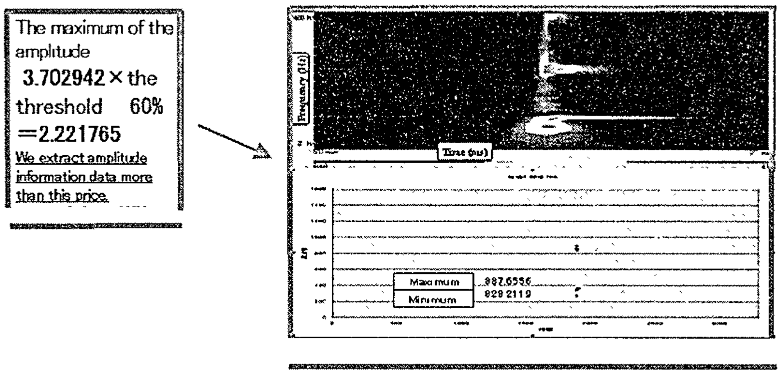


Fig.7 Extracted data for the maximum and minimum frequency over time.

extracted the values that were larger than the obtained value to numerize the image as shown in Table 2.

In addition, we examined the threshold value of the amplitude to obtain a reliable value. We compared the data at 10, 30, 60 and 90% of the threshold values with the wavelet transform image to determine the threshold value of the amplitude, then obtained the maximum, minimum and average values of the frequency spectrum using characteristic extraction of the frequency spectra as shown in Fig. 7.

Table 3 shows the maximum, minimum and average values of Japanese cypress and Japanese cedar specimens with different water contents.

We obtained the frequency component of the sound waves from the specimens with different water contents measured by weight from Table 3.

Figure 8 shows the changes in the frequency component of Japanese cypress with different water contents. The frequency components in the equilibrium moisture content region (water content below 15%) and below the fiber saturation point region (16 to 30% water content) showed similar values. The frequency spectrum in the range of 858 to 999Hz showed a strong signal strength (red) . On the other hand, the frequency component above the fiber saturation point region (water content above 31%) showed similar values. The frequency spectrum in the range of 296 to 533Hz also showed strong signal strength (red). The lower the water content of the wood, the higher the frequency component becomes. The water content of high quality wood has to be kept below 30%. In other words, the frequency component has to be above 850Hz. This means that high frequency water content measurement apparatuses do not show precise values in the most important water content region (around 30%).

Figure 9 shows the changes in the frequency component of Japanese cedar with different water contents. The frequency components in the equilibrium moisture content region (water content below 15%) showed values similar to Japanese cypress. The frequency spectrum in the range of 993 to 1115Hz showed strong signal strength (red). Below the fiber saturation point region, the frequency spectrum in the range of 839 to 1073Hz also showed strong signal strength (red),

Table 3. Maximum, minimum and average frequency values of Japanese cypress and Japanese cedar specimens with different water contents measured by weight.

No.	Maximum	Minimum	Average
A-1 (14%)			
A1-1	887	828	857
A1-2	887	828	857
A1-3	887	828	85
Total			857
A-2 (15%)			
A2-1	951	887	919
A2-2	984	857	921
A2-3	951	857	904
Total			915
B-1 (18%)			
B1-1	951	828	889
B1-2	951	828	889
B1-3	887	857	872
Total			884
B-2 (22%)			
B2-1	951	857	904
B2-2	1019	857	938
B2-3	887	857	872
Total			905
B-3 (25%)			
B3-1	1263	839	1078
B3-2	1263	839	1078
B3-3	1138	700	919
Total			999
B-4 (30%)			
B4-1	991	893	942
B4-2	991	893	942
B4-3	991	893	942
Total			942
C-1 (36%)			
C1-1	428	200	314
C1-2	887	828	857
C1-3	336	259	298
Total			490
C-2 (40%)			
C2-1	627	414	520
C2-2	672	414	543
C2-3	628	444	536
Total			533

No.	Maximum	Minimum	Average
A-1 (12%)			
A1-1	1026	958	992
A1-2	958	925	941
A1-3	1100	991	1046
Total			993
A-2 (12%)			
A2-1	1220	1062	1141
A2-2	958	958	958
A2-3	1263	893	1078
Total			1059
A-3 (15%)			
A3-1	1139	991	1065
A3-2	1179	1100	1139
A3-3	1179	1100	1139
Total			1147
B-1 (28%)			
B1-1	1139	991	1065
B1-2	1179	1100	1139
B1-3	864	864	864
Total			1023
B-2 (29%)			
B2-1	884	884	884
B2-2	834	805	819
B2-3	863	863	863
Total			839
B-3 (30%)			
B3-1	1179	1062	1121
B3-2	1179	1100	1139
B3-3	958	958	958
Total			1073
C-1 (35%)			
C1-1	778	569	674
C1-2	778	589	684
C1-3	778	496	637
Total			665
C-2 (42%)			
C2-1	654	417	535
C2-2	417	257	337
C2-3	417	266	341
Total			404
C-3 (50%)			
C3-1	513	316	415
C3-2	513	316	415
C3-3	479	275	377
Total			402

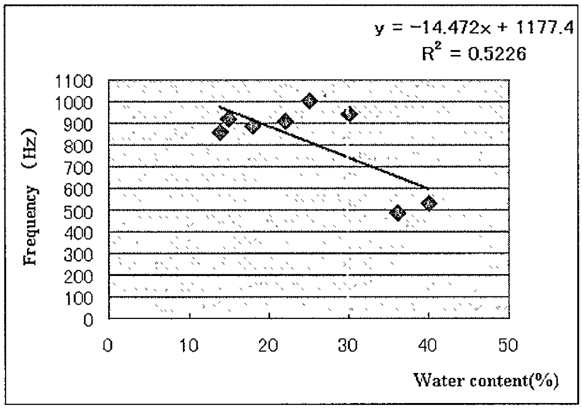


Fig.8 Changes in the frequency component of Japanese cypress with different water contents.

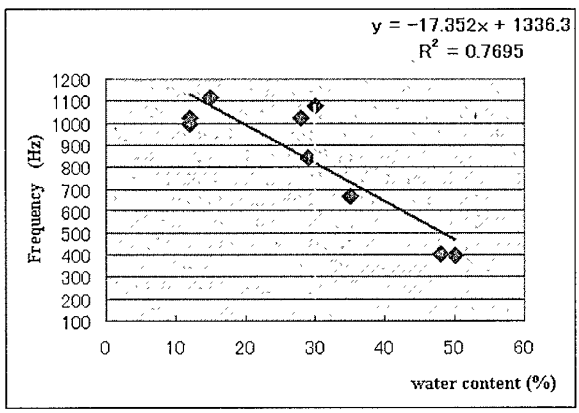


Fig.9 Changes in the frequency component of Japanese cedar with different water contents.
measure water content and observe defects inside wood lumber.

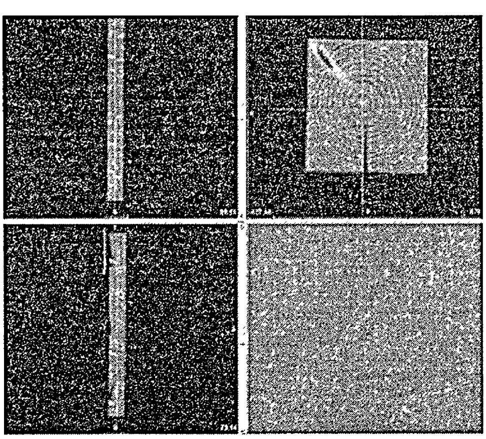


Fig. 10 X-CT of wood lumber with defects.

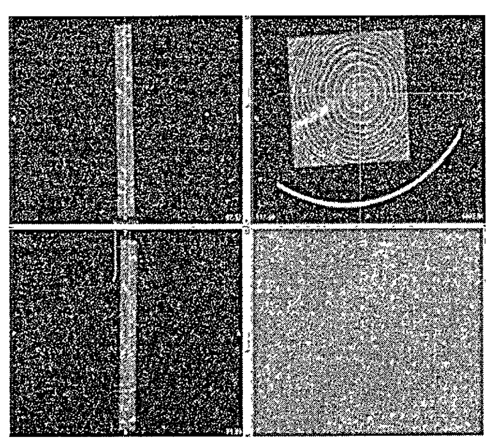


Fig. 11 X-CT of wood lumber without defects.

as did the region above the fiber saturation point, with a frequency spectrum in the range of 402 to 665Hz. Again, the lower the water content of the wood, the higher the frequency component becomes in Japanese cedar. The frequency also has to be maintained above 850Hz.

As a result, we measured the frequency component of the sound waves of specimens with different water contents using the weight method. The relationship between the frequency component of the sound waves and the water content of the wood lumber specimens showed good correlation. 24) -28) The frequency of tapping sounds above 850Hz showed that the water content of the wood lumber was below 30% (high quality).

We examined the "tailing phenomena," 29) -33) in which the frequency components appear over time in the wavelet transform image. We measured the Japanese cypress specimens using X-CT with and without the tailing phenomena as shown in Fig. 11 and 12, respectively. As a result, defects such as knots and/or holes were observed in specimens with tailing phenomena as shown in Fig. 11. Consequently, sound wave analysis can be used to measure water content and observe defects inside wood lumber.

4. Conclusion

The lower the water content of the wood, the higher the frequency component becomes in wood lumber. The frequency of tapping sounds above 850Hz showed that the water content of the wood lumber was below 30% (high quality). Sound wave analysis can be used to measure water content and observe defects inside wood lumber.

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References

1) Y. Imai, H. Kawai, K. Norimoto, T. Hirai, Quality of wood material science, Toyo publishing Co.,Ltd. p250-p256, (1997).
2) H. Ono, Y. Yokoyama, R. Ohno Architectural Institute of Japan, A collection of article reports pro-structure, No. 358,1 (1985), 373,1 (1987).
3) H. Ono, T. Yoshioka: Architectural Institute of Japan. papers, No..227,1 (1975).
4) M. Masuda: The No. 35 Japan wood research Society meeting for presenting research papers point, 1985, p176.
5) A 1975 synthesis technology development project, 1976, p82.
6) T. Sato, The measurement that used a non-linear effect, Corona publishing, Co,.Ltd, p6-p17, (1996).
7) A. Nagamatsu. Mode analysis and control of a sound・the vibration, The Musicological Society of Japan, Corona publishing Co,.Ltd, p6-p17, (1996).
8) W.C.Sabine,:Collected papers on acoustics, Harvard Univ. press, Boston, (1927).
9) Houtgast, T.and Steeneken, H. J. M: The modulation transfer function in room acoustics, Bruel & Kjiaer Technical Review, 3 pp,3-12, (1985).
10) Steeneken, H. J. M. and Houtgast, T. : RASTI : A tool for evaluating auditoria, Bruel & Kjaer Tachnical Review, 3, pp, 13-39, (1985).
11) P.S.Addison, The Illusstated Wavelet Transform Handbook, Institute of Physics,

2002, ISBN 0-7503-0692-0.

12) Ingrid Daubechies, Ten Lectures on Wavelets, Society for Industrial and Applied Mathematics, 1992,ISBN 0-8971-274-2.

13) P.P. Vaidyanathan, Multirate Systems and Filter Banks, Prntice Hall, 1993, ISBN 0-13-605718-7.

14) Mladen Victor Wickerhauser, Adapted Wavelet Analysis From Theory to software, A K Peters Ltd, 1994, ISBN 1-5881-041-5.

15) Gerald Kaiser, a friendly Guide to Wavelets, Birkhauser, 1994, ISBN, 0-8176-3711-7.

16) Association of Japanese Non Destructive inspection: A non-contact supersonic wave serious wound special feature, 34 (11) , pp.781-819 (1985).

17) Arai · Hagihara · Nagabutch: Vibration noise analysis in the compartment that used sensitivity analysis,12 pp.545-550 (1988).

18) Y.Toda : The development of a sensor for highly precise speed of sound measurement, A sound elasticity meeting for the study, 2, pp.31-36 (1989).

19) H. Hamada : The basics of adapter filter (The 1), An acoustics bulletin, 45-8, pp.624-630, (1989).