SOURCE LOCATION METHOD FOR GFRP WIND TURBINE BLADE USING ACOUSTIC EMISSION SIGNAL MAPPING

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1 Introduction

Recent social issues related to energy crisis and environmental pollution caused a concern for the renewable energy sources. One of the promising future energy, wind energy is taking its place as an alternative energy and the market of wind turbine system is growing steadily. Moreover wind turbine blades are getting large in size due to the demands of high power wind turbine application [1]. As wind turbine blades increase in size, there is an increasing need to monitor the health of the structures [2, 3].
And also they use composite materials in manufacturing blades for ensuring weight vs. strength ratio, appropriate nondestructive testing method for evaluating the integrity of composite material structures is required. There were many studies for the applying acoustic emission technique to composite blades in the Europe. But these research theme was mainly focused on evaluation of structural integrity during static and fatigue test [4], and it was used as a tool for detection of damage occurrence [5].
Recently, there have been advances in developing damage localization method in composite materials using a structural neural system [6], and in monitoring of acoustic emission from real wind turbine blades undergoing static and fatigue testing [7]. However these methods usually used a number of sensors in their system, since there exists a practical problem for real application as large blades. It is clearly important to detect the location and severity of any damages which occurs during the static test in order to be able to improve blade design and also to monitor such areas during the fatigue test. Conventional source location technique has used typically arrival time difference between elastic waves generated from each separated sensor mounted on the structure surface. However, in the case of composite materials or heterogeneous structures consisted of each different material, it is very hard to find the location of damages exactly.
This study describes a new concept for identification of damage sources in heterogeneous composite materials and discusses how they can be verified both to laboratory blade certification testing and to actual full scale wind turbine blade. Finally we suggest a new algorithm for source location of damages and verified its usefulness in field application.

2 Acoustic emission signal mapping method for damage location

2.1 Damage index map

Usually the limitation of traditional AE source location method strongly showed the dependence for wave speed in the corresponding material of tested structures, especially in the inhomogeneous material or heterogeneous structures. Therefore new method to be considered should be less affected by the wave speed in these kinds of composite blades. Also it will be better to install minimum number of sensors on the structures to be covered. In order to satisfy these conditions, we developed a new source location algorithm using damage index based database map.
Database map is consisted of each intensity value acquired from pre-set data point on the blade surface before installing the blade onto the tower and nacelle. Considering several kinds of damages, each different arbitrary input source was used to get initial database map. Each value of database was calculated from power spectrum density of the signal after measuring AE events. That is, the measurement of signal energy changes in the composite materials is better than time arrival method in its reproducibility point of view.

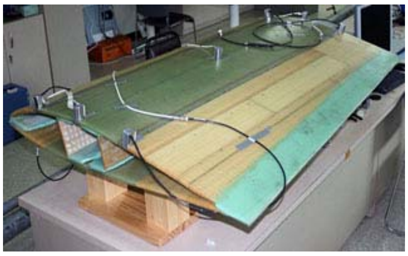


Fig. 1 Test specimen : a part of 750 kW blade

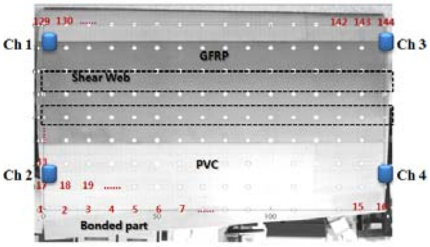


Fig. 2 Sensors and test point on the specimen

That is, the energy changes of AE signal is less affected than the measurement of arrival time difference in location damage source of composite materials. Fig. 1 shows the specimen for algorithm verification test and Fig. 2 shows the position of sensor and data point to be tested. Four sensors are used to get one signal map of database of blade area interested. In case of the Fig. 2, total four sensors and 144 test points was used to calculated intensity and constructs a signal map of blade to be tested. From the several steps of signal processing, signal map was completed for each sensor. The signal map indicates a pattern of signal attenuation according to the position of sensor and input source.

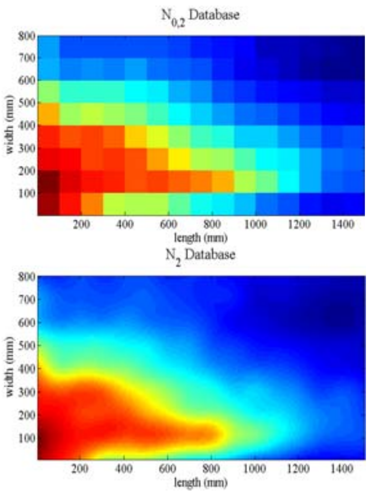
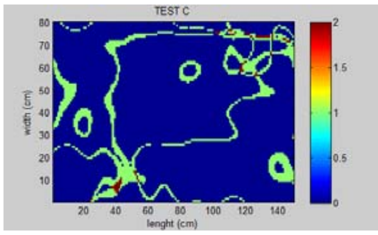


Fig. 3 Enhanced resolution of the signal map by applying interpolation process

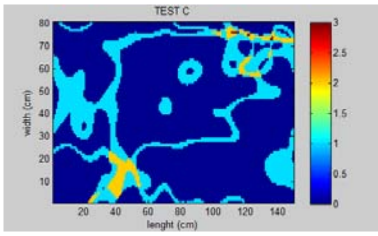
Fig. 3 shows the result of interpolation process. Interpolation process of signal map will minimize source location error by increasing signal map resolution.

2.2 Procedure of source location

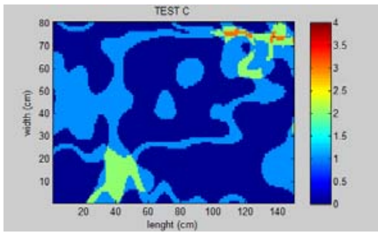
Now, the database of signal map acquired from the tested blade will be used to calculate the location of unknown damage sources. Basic principle of this method is to find a solution by comparing certain value between each four sensor output and pre-acquired database of the interested blade. In these procedures, some numerical process such as iteration method, adding tolerance, error correction can be applied to optimize source location exactly shown as Fig. 4. It means that this numerical process helps source location area smaller by increasing measured damage index value based on tolerance concept. And also, this procedure covers the problems of unexpected foreign input sources which are different from initial input source.



(a) 2 % tolerance



(b) 5 % tolerance

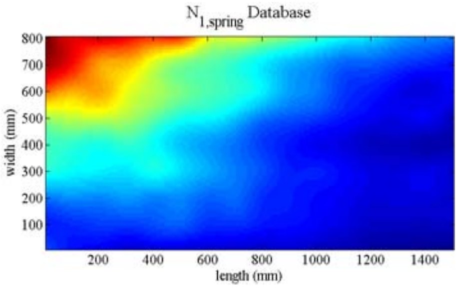


(c) 8% tolerance

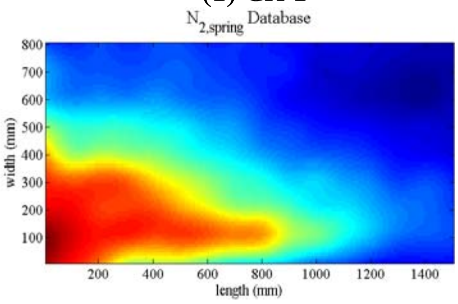
Fig 4. Damage location result with increasing tolerance

3 Experiments for verification

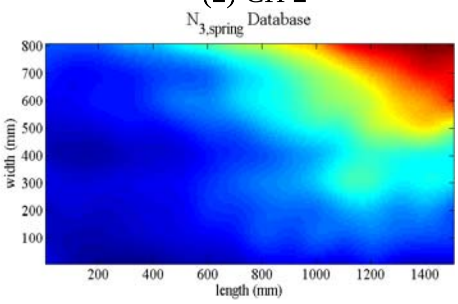
Verification test for new suggested location algorithm was carried out in the laboratory specimen test and in the full scale blade test. The specimen of laboratory consisted of 1,500 mm in length, 1,000 mm in width and is a part of actual full scale blade. In the full scale test of blade which is a 25 m in length, 750 kW capacity, the pressure side of the blade was used as test area.



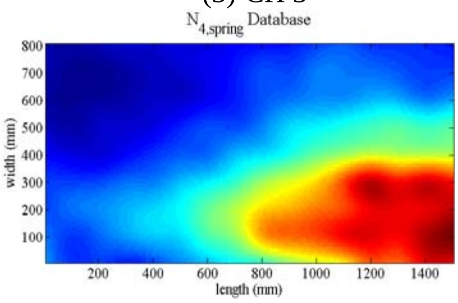
(1) CH 1



(2) CH 2



(3) CH 3



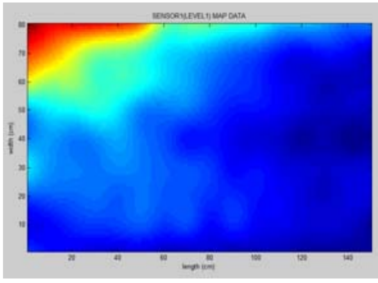
(4) CH 4

Fig. 5 Signal map by each different channel

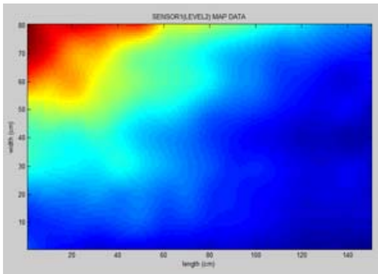
3.1 Experiments for the laboratory specimen

In order to verify the performance of new suggested localization method, traditional acoustic emission source location method was tried together. Same four AE sensors were used and wave speed was directly obtained from same blade. Measurement of wave speed in the blade was done for three different materials such as GFRP, PVC and GFRP-PVC area. Therefore three kinds of different wave speed were used to calculate reasonable source location. The database of signal map was measured from 16 points in row, 9 points in column, 100 mm interval, that is, total 144 points. Also we composed the 12 signal maps, which are each different input source such as spring impact, pencil lead break, equo-tip test.

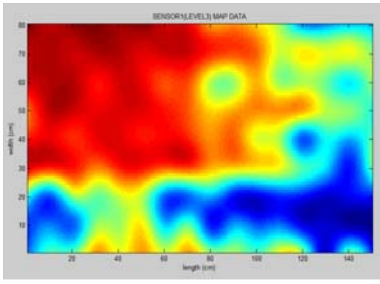
Fig. 5 shows the signal map of each different channel for the same impact source. On the other hand, Fig. 6 shows the signal map of same channel for the each different impact source.



(1) Pencil break



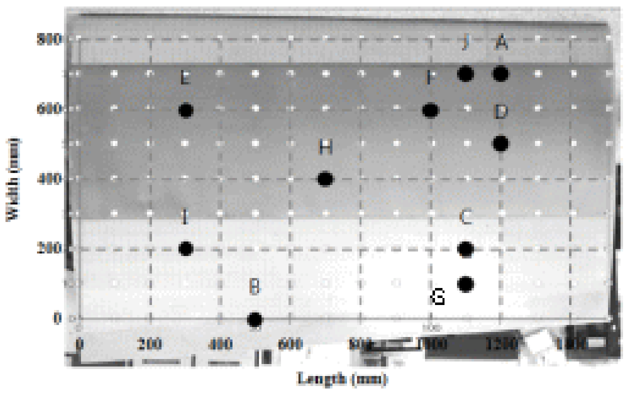
(2) Spring impact



(3) Equo-tip D type

Fig. 6 Signal map by each different source input

After completion of signal map, we carried out arbitrary unknown source location test. Fig. 7 shows type and location of the unknown arbitrary source. It is consisted of same or different source by comparing the signal map source.



A / B	- Spring impact
C	- D_type equo tip impact
D / I	- Pencil break
E	- G_type equo tip impact
F / H	- Steel bar impact
G	- Steel ball drop (200 mm)
J	- Plastic hammer drop (200 mm)

Fig. 7 Type and location of arbitrary damage source for location test

Table. 1 Test result of arrival time difference method

Impact Source	Time arrival difference method(x, y)						Error (mm)
	v=1165 m/s		v=894 m/s		v=763 m/s		
A	Fail		Fail		900	800	316
B	Fail		Fail		Fail		Fail
C	850	150	850	250	800	250	271
D	1300	450	1100	450	1050	450	127
E	600	550	Fail	Fail	650	500	334
F	850	650	800	550	800	500	196
G	850	200	850	250	825	275	296
H	750	375	750	375	750	375	56
I	Fail		550	50	600	100	304
J	900	625	850	625	850	600	248
							Total avg. > 239

Table. 2 Test result of signal mapping method

Impact Source	Test Point(x, y)		Signal mapping method (x, y)		Error (mm)
A	1200	700	1000	600	224
B	500	0	550	50	71
C	1100	200	1350	100	269
D	1200	500	1300	550	112
E	300	600	300	300	300
F	1000	600	1100	500	141
G	1100	100	900	100	200
H	700	400	700	400	0
I	300	200	300	100	100
J	1100	700	1200	700	100
					Total avg. = 152

Table. 1 ~ 2 shows that the results of comparison of location error between new suggested and traditional AE source location method. One of the remarkable result shows that traditional source location using the arrival time difference method was not available in the case of A and B impact sources. On the other hand, new method could find the exact location in the whole test. And the result also shows that new suggested method was much excellent compared with traditional method through whole test results.

3.2 Experiments for the full scale blade

Fig. 8 shows full scale each sensor attached on to the blade surface and Experiment was done in the similar manner as laboratory verification test above. In this experiment, we have used two different AE sensors (30 kHz, 60 kHz resonant type) which also consists rectangular location grouped by each four sensor

The initial database signal map was measured from intersection of 21 in row, 18 in column which is 100mm internal and total 378 points. We composed the 12 signal maps from 3 different input sources such as equo-tip C / D / G type tester shown as Fig. 9. This tester has small tip that is moving inside of them and it has 3.1 g, 5.4 g and 23.2 g weight respectively. These three types of tester generate elastic wave with different energy by sudden release of tip.

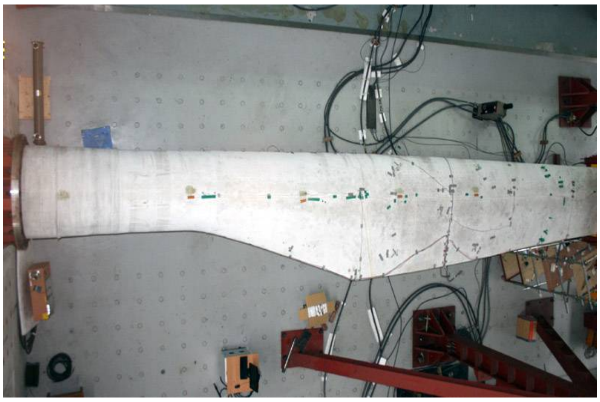


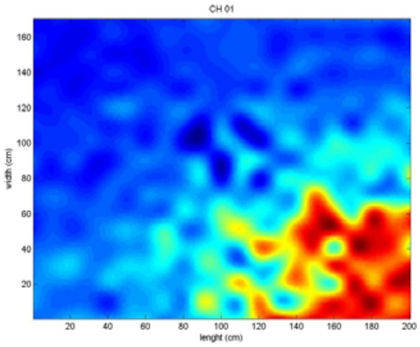
Fig. 8 25 m Full scale wind turbine blade

Fig. 9 Equo-tip tester ; C / D / G type from top

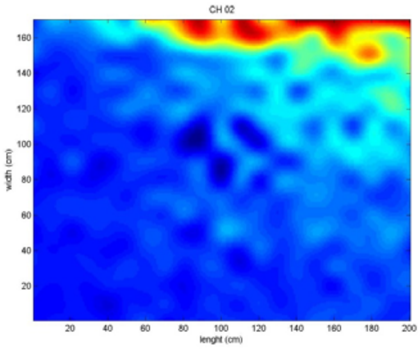
Fig. 10 shows the signal map obtained from equo-tip D-type source and 60 kHz AE sensor. This full scale blade is already damaged by previous static and dynamic test. So, the signal map measured on this blade shows a little distorted map compared with sound blade.

After completion of signal map, we also carried out arbitrary source location test. This test acquired with two sensor groups (30 kHz, 60 kHz). The location of unknown source shows Table. 3 which are same signal shows Fig. 7

We obtain the source location error shows table. 3 by applying damage index value to each different map group, and this procedure processed with source location algorithm. By the result of table. 3, the average values of smallest error by each sensor group are similar. It means that we can reduce the error by selection of optimal map group. And this procedure does not depend on the type of AE sensors. So, we just consider only background noise and target area size without selection of AE sensor type when we build up the SHM system.



(1) CH 1



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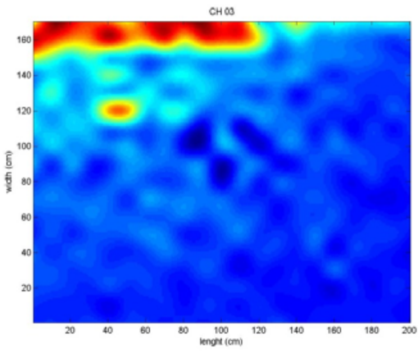
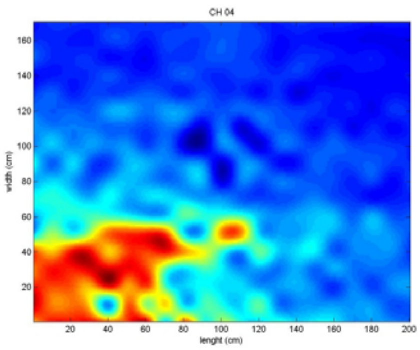


(3) CH 3



(4) CH 4

Fig. 10 Signal map of 25 M full scale blade by each different channel

Table. 3 Error value for different map group

Damage type	Location (mm)		Error for map group (mm)					
			Sensor A(30 kHz)			Sensor B(60 kHz)		
			Map group					
	x	y	C	D	G	C	D	G
A	400	1250	187	53	9	92	63	76
B	600	500	113	192	148	345	99	115
C	700	300	193	196	116	153	57	78
D	1000	550	93	155	69	159	105	21
E	1200	200	188	110	68	473	144	342
F	1200	950	73	67	33	232	49	80
G	1700	650	211	192	272	47	158	164
H	1800	1350	127	104	84	155	67	159
I	1200	1450	102	116	68	50	55	64
J	950	1650	197	188	129	145	143	71
Avg.			**148**	**137**	**99**	**185**	**94**	**117**

4 Conclusions

This study describes the new concept of signal map algorithm for identification of damage sources in heterogeneous composite materials. And we discuss how they can be verified both to laboratory blade experiment for certification and to actual full scale wind turbine blade. From the experiment for certification, the results show that new suggested source location algorithm has much higher performance than traditional AE source location method.

Acknowlegments

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