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Overview of Japanese Smart Materials and Structures System Project

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The Japanese "Smart Materials and Structures System" Project was implemented, as a five-year project, from 1998 through March 2003. The METI funded this project and the NEDO, New Energy and Industrial Technology Development Organization, entrusted the research activity to RIMCOF.

This project consisted of four fundamental research activities performed by the respective four groups that were the "Structural health monitoring", the "Smart manufacturing", the "Active adaptive structures", and the "Actuator materials and devices". In addition to the above, two concept demonstrators were manufactured and tested, in order to integrate the sensor and actuator system elements developed by this research activity into a smart composite structure, to evaluate the validity of the system. Both demonstrators were made of CFRP composite structure, which had cylindrical shape like a scaled down aircraft fuselage with 1.5 meters in diameter and 3 meters long. The first one demonstrated the damage detection and damage suppression function, and the second one demonstrated the suppression ability of both of structural vibration and inside acoustic noise of the cylindrical fuselage. This paper outlines the research activities and the results on the demonstrator test, together with the research and development organization.

Key words: Smart Materials, Composite Structure, Damage Detection, Damage Suppression, Noise and Vibration

1. AIM AND CONTENTS OF R&D

From a viewpoint of saving resources and energy, giving an intellectual function to material and structures is expected for improvement in its reliability. The full-scale application of an advanced composite material helps to achieve weight saving of an air vehicle and a high-speed transportation system.

The composite material has the advantage in giving an intellectual function, which can perform the material design in its fiber layout and in making it as multi-function, etc.

This project is aiming to develop the base technology for realization of the material & structures system, which gave intellectual functions as a new material of the next generation. The material system "The Smart Material & Structures System", which performs information processing and control will have the ability as like a living matter in consciousness, judgment, and response. The system unites the sensor elements (nerve) and actuator elements (muscles) in an advanced composite material, which full-scale employment in the industries will be expected in the future.

2. R&D ITEMS AND ORGANIZATION

R&D of The Smart Material & Structures System included four fundamental research themes, which were (1) Structural Health Monitoring Technology, (2) Smart Manufacturing Technology, (3) Active and Adaptive Structure Technology, and (4) Actuator Materials and Devices. In addition to the above four themes, the Demonstrator Test program was introduced from the third year and was carried out for verifying the result of these four fundamental researches in integration to smart material and structures system (Fig. 1).

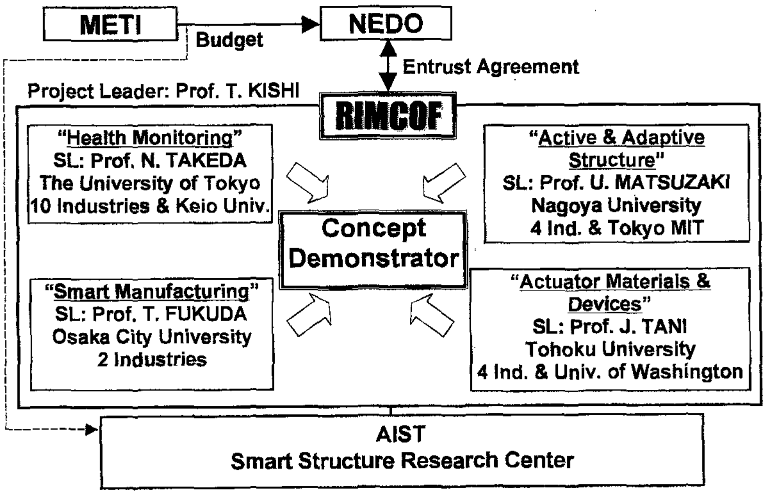

Fig.1, The Enforcement Organization

Under the Project Leader professor Teruo Kishi, four professors, who were (1) professor Nobuo Takeda, the University of Tokyo, (2) professor Takehito Fukuda, Osaka City University, (3) professor Yuji Matsuzaki, Nagoya University, and (4) professor Junji Tani, Tohoku University worked as the Sub Leaders.

The enforcement organization was based on the network where 16 companies, one research organization, seven universities, and one national research institute participated centering on the four Sub Leader professors.

3. CONTENTS OF R&D, AND ITS RESULT

3.1 The fundamental research

In research of the Structural Health Monitoring Technology of a composite structure, it inquired for the purpose of development of (a) high performance sensor system technology, (b) structure self-diagnosis and damage suppression technology, and (c) the application technology to real structure. And the small diameter optical fiber sensor of polyimide resin coated 40 micrometers in diameter of clad was realized for the first time in the world. The detection technology of transverse cracks and delamination, the damage suppression technology using shape memory alloy foil embedded in a composite material, and the impact damage detection technology of a composite material with difficult visual discovery etc. was developed.

With the Smart Manufacturing Technology, it inquired for the purpose of development of (a) the smart manufacturing process technology, and (b) the embedding technology of sensor and actuator to the mother composite material. And the multifunction sensor, by which detection of both of a resin flow front position and the degree measurement of curing of matrix resin are possible, in RTM process was developed prior to the world.

It inquired for the purpose of development of (a) the adaptive control system technology of a structure, and (b) the application technology of the system to a complicated structure element, in research of the Active and Adaptive Structure Technology. And vibration and shape control of a flexible structure antenna, increase of vibration attenuation in a flat structure object of 20% or more, and reduction of radiated acoustic power of 30% in overall frequencies up through 500Hz, etc. was successfully achieved.

Moreover, in development of the Actuator Materials and Devices, it inquired for the purpose of development of (a) high performance ceramic actuator material, and (b) high performance shape memory alloy. And functionally graded piezoelectric actuators as a bending type with high durability more than the twice of bimorph type, piezoelectric fiber which has a metal core, rapid-response shape memory alloy with a transformation temperature difference of about 10 degrees C, etc. were developed.

3.2 Demonstrator test

The Demonstrator test was performed in order to prove that it was the world level of the research, and the result of the above four fundamental researches could be unified and applied to real structure.

3.2.1 Test items of proving

The test items were chosen by the following four judgment standards, and were narrowed down to seven items as shown in the Table I.

1) It should be advanced technology
2) There is user needs applied to the aircraft fuselage for the future
3) The fundamental research results can be verifiable by Demonstrator test
4) Possible in the project schedule

Table I, The test items

	Category	Proving Items
1	Impact Detection	Real Time Impact Damage Detection using embedded Optical Fiber Sensors
2		Real Time Impact Detection using Integrated AE Sensors Network
3	Strain Detection	Strain Distribution Measurement in wide area using BOTDR* Sensors *Brillouin Optical Time Domain Reflectometer
4		Strain history Memory by electric conductivity change in Smart Patch (CFRP sheets)
5	Damage Suppression	Damage Suppression System using Embedded SMA Foils in CFRP structure
6	Smart Mfg	Smart Manufacturing of Low Cost Integrated Panel by Smart RTM
7	Active Adaptive Structure	Noise and Vibration Reduction Technology in Aircraft Internal Cabin Reduce cabin noise by 3dB or more

3.2.2 Outline of the Demonstrator

Two kinds of Demonstrators were planed and manufactured (two bodies). The test items 1-6 were to be verified using the Damage Detection and Damage Suppression Demonstrator, and the test item 7 was to be proved by the Noise and Vibration Reduction Demonstrator.

The two demonstrators were made of the composite material structure with a cylinder shape, the same size, which had 1.5m in diameter and the length of 3m. It is about one third of diameter of a small class passenger airplane like B737.

3.2.3 Tests and the result

A. Damage Detection and Damage Suppression Demonstrator

The impact position and degree of the damage generated by a hammer weight dropped on the upper surface of the Demonstrator were judged correctly. Further, an AE sensor network system attached to the Demonstrator successfully identified the position of the impact generated by the hammer tapping with the location accuracy within 1cm error. (Items 1 and 2)

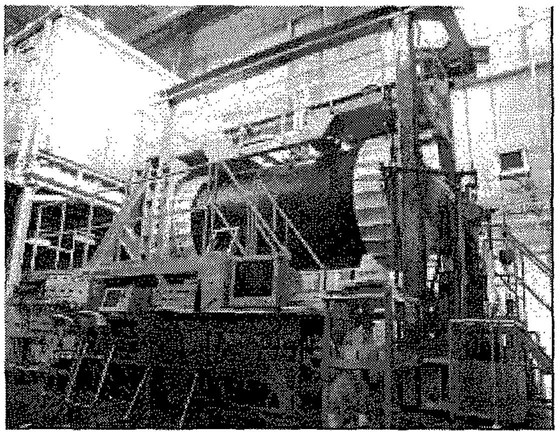

Fig.2, Damage Detection and Damage Suppression Demonstrator

The Demonstrator was set up one end to a fixture frame as cantilever style (Fig.2), and the other free end had jack points to apply bending moment. While jacks applied bending moment to the Demonstrator, improved BOTDR system successfully measured the distributed strain of the structure in the accuracy within 100 micro strains of error. The accumulated strain detection of the structure and its memory using the CFRP Smart-Patch was performed successfully.

The damage suppression effect of SMA embedded structure was demonstrated and was proved that the 30% improvement in the first transverse crack occurrence strain level. Such like the first crack occurred at 3200 micro strains at the Smart Structure area or SMA embedded area, while 2500 micro strains at the conventional CFRP area. (Items 3, 4, and 5)

It was proved that the optical fiber sensor embedded in the pressure bulkhead panel manufactures by smart RTM process measured strain correctly when it was exposed pressurization inside-of-the-body up to 0.75 atmosphere. (Item 6)

All the test items were proved like the above.

B. Noise and Vibration Reduction Demonstrator

The frequency range of 0-500Hz noises were applied to the Demonstrator using speakers 1m distances from exteriors of the Demonstrator, which was hung from the ceiling in an anechoic room, and the noise of inside-of-the-demonstrator was measured. (Fig.3)

Fig.3, Noise and Vibration Reduction Demonstrator

By sensing and actuating of structural vibration using PZT piezoelectric devices, the structural vibration and internal noise pressure were controlled and reduced.

As a result, structural vibration attenuation factor improvement by 31% was proved, and internal noise reduction of 4dB was achieved.

4. CONCLUSION

This research-and-development project carried out for five years from 1998 fiscal year was finished successfully at the end of March of this year, 2003.

I believe that the Structural Health Monitoring Technology and the Smart Manufacturing Technology progressed to the level by which a future utilization image comes into a view. On the other hand, the Actuator Materials are still not enough in capability in respect of real application to an industrial field although there were fruitful results obtained with various actuator materials.

In realization of the smart actuator, a future dream, I hope that material researchers who make new material, end users who pull out needs, and system researchers who mediate between material researchers and end users should serve as the Trinity in the research, and their wisdom should be cooperatively considered effectively.

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