Non-destructive Inspection of Solid Rocket Motors Using Air-coupled Ultrasonics

Hideyuki KURABAYASHI, Hiroyuki YAMAGUCHI*, Hideyuki SHIONO
Akiyoshi SATO,Masashi MINATO
IHI AEROSPACE Co.,LTD,JAPAN
Eiichi SATO
JAPAN AEROSPACE EXPLORATION AGENCY

ABSTRACT

A new automatic Non-destructive Inspection method using Air-Coupled Ultrasonics(Non-contact method) to judge the health of Solid Rocket Motor(SRM) has been developed and utilized in the actual SRM..

Air-Coupled Ultrasonics need high Signal-Noise ratio because damping of ultrasonic in transit is high. Adoption of chirped pulse and cross-correlation process which bring dramatically improvement of Signal-Noise ratio. Then the technique comes to the level that enable to guarantee the products.

In this paper, detail ultrasonic element technology and installation to the SRM has developed by ISAS/JAXA(Institute of Space and Astronautical Science / Japan Aerospace Exploration Agency) are introduced.

1.INTRODUCTION

In the space development of Japan, Solid Rocket Motor(SRM) is used as Solid Rocket "M-V" is the world's biggest to launch science satellites and surrounding rockets. The structure of SRM, which is shown in Fig.1, is laminated structure by motor case(pressure vessel) of metal or Carbon Fiber Reinforced Plastic, insulation of rubber, and propellant is fuel.

Table1 shows Critical factors of SRM. Some flaws what we need to mainly take care are a void and a delamination. These flaws have a possibility of motor burst during a flight, because these flaws make increasing of combustion area. This cause rising of inner pressure, and ultimately lead to motor burst.

Conventionally, the inspection method to detect these flaws is most utilized the x-ray inspection. But with increasing of SRM size, the cost of X-ray of the inspection detector and the facility keep getting higher. As alternative low-cost inspection, ultrasonic inspection is applied.

In this paper, the example that the ultrasonic inspection method applied to flight model SRM which aims to guarantee equal level with the conventional x-ray inspection is mainly introduced.

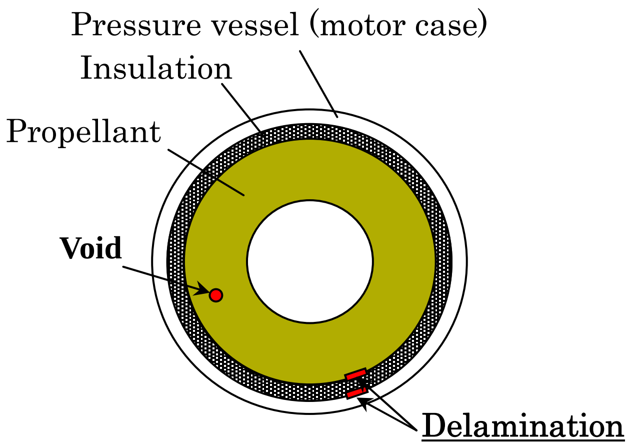

Fig. 1. Cross-section shape of solid rocket motor and critical flaw

Table 1. Critical factors of SRM

Factors	Possible phenomenon	Reason	Inspection method
Void	Motor burst	Increasing of combustion area ↓ Pressure rising	X-ray
Crack			
Delamination (Propellant / Insulation)			
Delamination (Insulation / Chamber)	Motor burst	Inflow hot gas ↓ Increasing of combustion area ↓ Pressure rising	X-ray
Hole in the motor case	Damaging of external devices	Inflow hot gas ↓ Leaving a hole of chamber	Hydro proof test

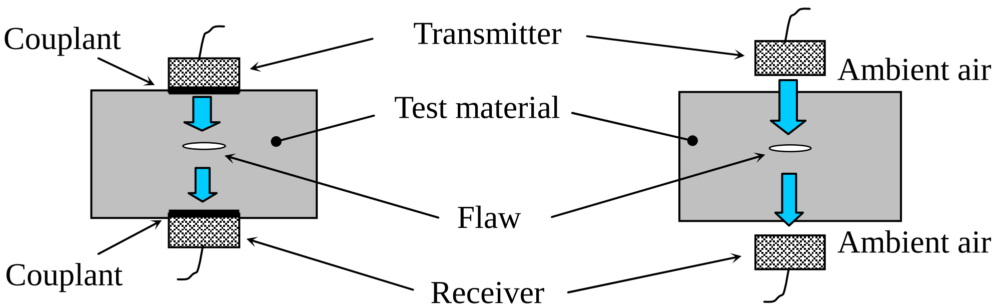

Fig. 2. Contact method

Fig. 3. Non-contact method

2. ULTRASONIC INSPECTION METHOD

2-1. Deference between contact and non-contact method

Ultrasonic inspection methods, which is shown Fig.2, are two methods to transmit through the test material. One is contact method, the other is non-contact method. In these methods, ultrasonic transmitted by one probe and received by the other probe through the test material. Ultrasonic wave have the characteristic which is to generate acoustic dumping at the boundary surface of different materials. So, as compared to the healthy part, ultrasonic dumping is detected by the interruption on the flaw part.

In the perspective of reducing the inspection costs, the automation of the inspection detector is the important factor. Conventionally, contact method had been used for the inspection of SRM. However, this method needs some couplant, so the inspection needs a lot of time because acoustic coupling don't become stable between probes and the test material.

The non-contact method is better suited for automatic scanning because ultrasonic is transmitted through the air. However, acoustic impedance of the air is much lower than the other materials, so it causes high acoustic dumping. The acoustic dumping at boundary face of different materials is expressed by the formula which is shown (A). The wave energy of incoming to the boundary face is E_i , The energy through the boundary face is E_t , and acoustic impedances of each materials are Z_1, Z_2 .

$$E_t / E_i = (4Z_1Z_2)/(Z_1 + Z_2)^2 \qquad \cdots \quad \text{(A)}$$

For example, if the test material is propellant, there is the difference "-190dB" calculated by formula(A) of acoustic dumping between contact method and non-contact method. In the example above, non-contact method has a demerit that ultrasonic through the boundary face of the air is extremely slightly.

Non-contact ultrasonic detector which is shown in the next section can discriminate the slight ultrasonic by using advanced signal processing.

2-2. Non-contact ultrasonic detector

On the occasion of application of non-contact method to production of SRM, NCA1000 manufactured by SecondWave is used for ultrasonic detector. The exterior of the detector is shown Fig.4. As described in the 2-1 section, received intensity is extremely slightly in non-contact method. But NCA1000 can detect the slight ultrasonic by using chirped pulse and cross-correlation process which bring dramatically improvement of Signal-Noise ratio. The typical wave form of chirped pulse is shown Fig.5.

Table 3. Acoustic damping of each methods

	Contact	Non-contact
Interface between probes and propellant	-52dB	N/A
Interface between probes and air	N/A	-112dB
Interface between air and propellant	N/A	-130dB
total	**-52dB**	**-242dB**

(**Annotation**:These numerics are doubled in consideration of transmitting and receiving.)

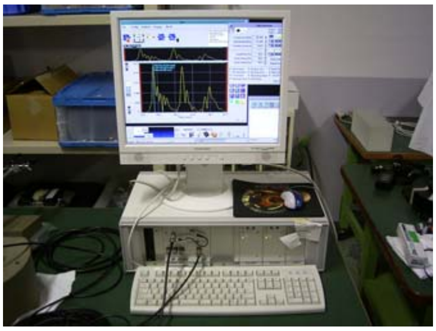

Fig. 4. Exterior of NCA1000

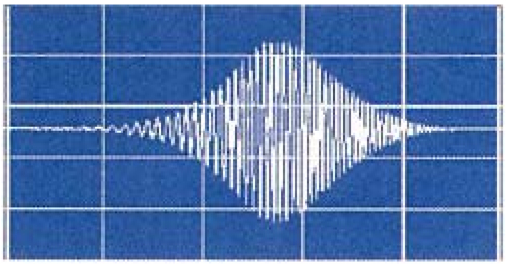

Fig. 5. Typical form of chirped-pulse

Fig. 6. Exterior view of S310

Table 3. Specification of S310

External diameter	ϕ310mm
Allover length	7000mm
Motor-case(metal) thickness	2mm
Propellant thickness	100mm
Insulation thickness	4 – 21mm
Weight	700kg

3. Application of non-contact method to SRM

In the inspection by non-contact method this time, the target SRM is "S310". Fig.6 shows the exterior and Table.3 shows the specification of S310. This SRM has developed by ISAS/JAXA(Institute of Space and Astronautical Science / Japan Aerospace Exploration Agency), the main purposes are observations of aurora and ozone shield etc,. Until now, the launch of this SRM has achieved 39 times.

3-1. Confirmation of inspection configuration

On the occasion of application to SRM, the inspection configuration is confirmed.

3-1-1. Selection of probes

The propellant and insulation of SRM are known as high acoustic dumping materials. In the frequency band of a few MHz that is generally used for metals, acoustic dumping by materials and transmission distance is too high to detect transmission waves. But it is indicated that it became possible by using low frequency probe like Fig.7 by MIHARA.1)

The propellant thickness of S310 is approximately 100mm like Table.3. So the probe of 100kHz is selected for the inspection.

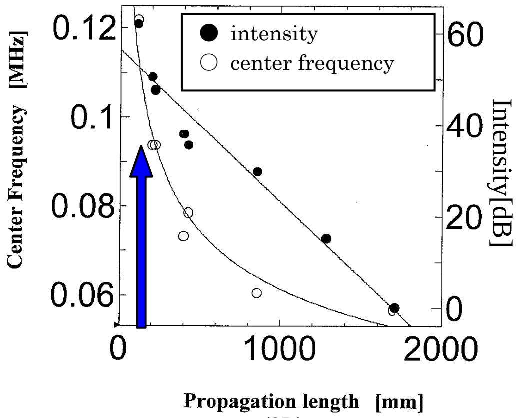

Fig. 7. Characteristic of received intensity and center frequency[3)]

3-1-2. Confirmation of detection ability for flaws

We confirmed the detection abiliity for flaws in non-contact method by selected probes.

ｉ. Detection ability for delamination

Detection ability for delamination was confirmed by production of SRM. The allocation of probes shows Fig.8, transmitter is inside and receiver is outside of SRM. As imitation delamination, urethanes, these sizes are ϕ15, 20, 25, 30, and 35mm, are set on the motor case. So, airspace is made between the urethane and the motor case like delamination. The configuration shows Fig.9. We obtained received intensity of each points according to scanning the probes to axial and circumference direction. Fig.10 shows the result. As the result, we confirmed about 5dB decline of receiving intensity at artificial flaws more than ϕ25mm.

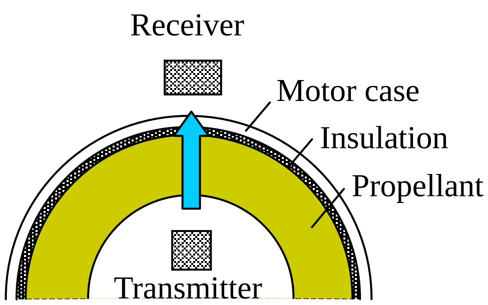

Fig. 8. Configuration of probes

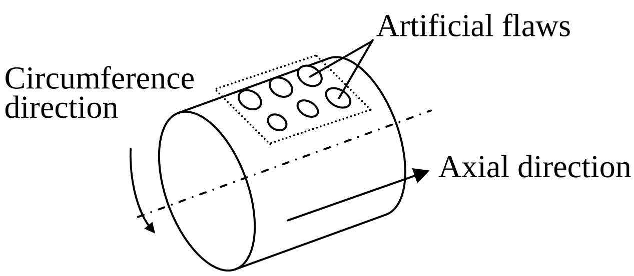

Fig. 9. Configuration of artificial flaws

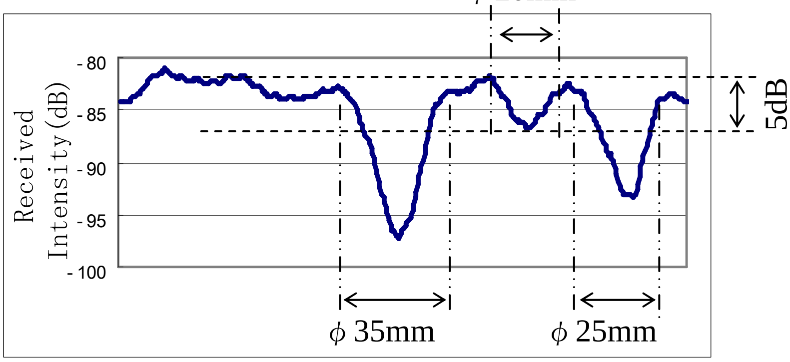

Fig. 10. Transition of transmitted intensity

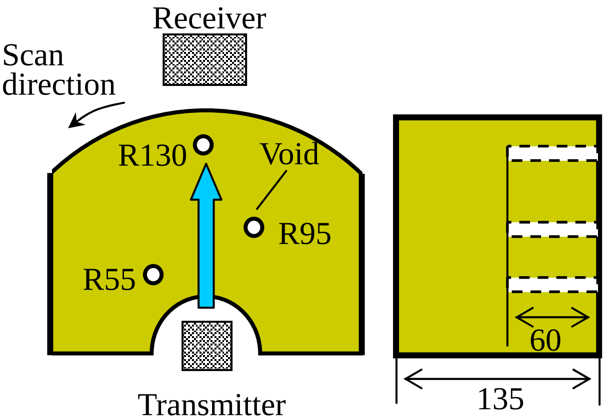

Fig. 11. Configuration of dummy propellant

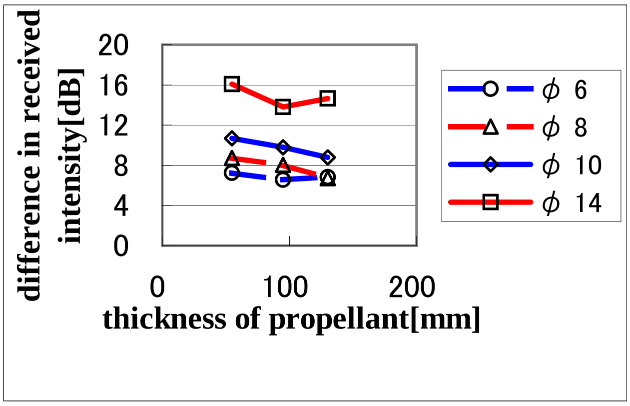

Fig. 12. Detection performance of voids

ⅱ. Detection ability for void

Detection ability for void was confirmed by four test pieces made for dummy propellant. The size of test piece is assumed as S310. Fig.11 shows the shape. Each test pieces have artificial flaws of ϕ6, 8, 10 and 14mm. We obtained receiving intensity by rotating the test piece like Fig.11. Fig.12 shows the result. On the ϕ 6mm, there is about 6dB difference for healthy part.

As ⅰ and ⅱ mentioned above, it is confirmed that the detector can find the acceptable size of flaws being tolerated by S310.

3-2. Ultrasonic inspection system

3-2-1 system summary

On the occasion of SRM inspection, we developed inspection system which could scan automatically by non-contact method. Fig.13 shows block diagram of the system, and Fig.14 shows aspect of inspection. The actuators controlled PC scans probes in axial direction and rotates SRM. So, received intensity is saved automatically according to automatic scanning.

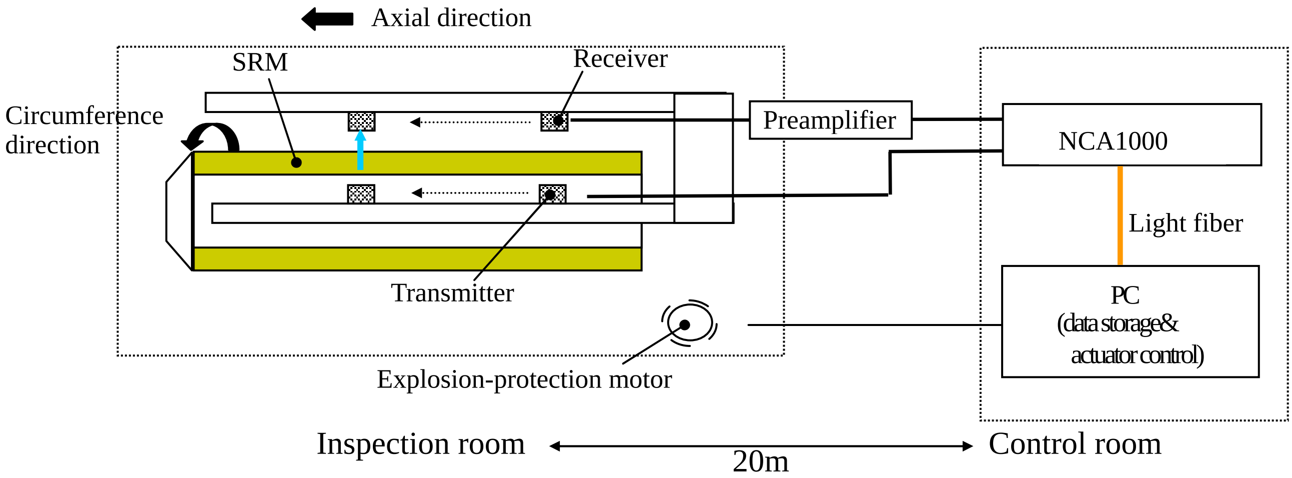

Fig. 13. Block diagram of Inspection system

Fig. 14. Inspection situation

Probes	Transmitter:100kHz(40mm) Receiver:100kHz(65mm)
Ultrasonic detector	NCA1000(SecondWave)
Scan pitch	axial:20mm circumference:9deg(approx 24mm)

Table 5. Inspection configuration

3-2-1 Protection against noise

As already mentioned in chapter 2-1, acoustic damping of the Non-contact method is much higher than the contact method usually used. So high receiving sensitivity is required to catch the slight signal going through the SRM. However, high receiving sensitivity is also sensitive to noise, the protection methods showing below are conducted.

1) Noise from Explosion-protection motor

Noise occurred by Explosion-protection motor effects the detector and it decreases the Signal-Noise ration. By changing the communication method from analog form to light fiber form, the detector is isolated from Explosion-protection motor and PC(controller) electrically. Compared to the metallic cable, the light fiber can exclude the noise more efficiently and lead to increment receiving intensity.

2) Noise from Long cable

The cable length between the receiver and detector is about 20m. While the signal transmittin along the cable, the decay of signal intensity and influence of extrinsic noise affect the Signal-Noise ration. By introducing the preamplifier, 2m from receiver, to turn up the signal level immediately, receiving intensity has been improved.

3-3. Result of application

Fig.15 shows the shape of S310. The cross section of S310 in the after part is different from the cross section in the forward part. In the forward part, the cross section is round shape. And in the after part, the cross section is star-shaped. The reason of this difference is to assure constant combustion area. Table.5 shows inspection configuration. As imitation delamination, urethane, the width is 20mm, is set on the motor case.

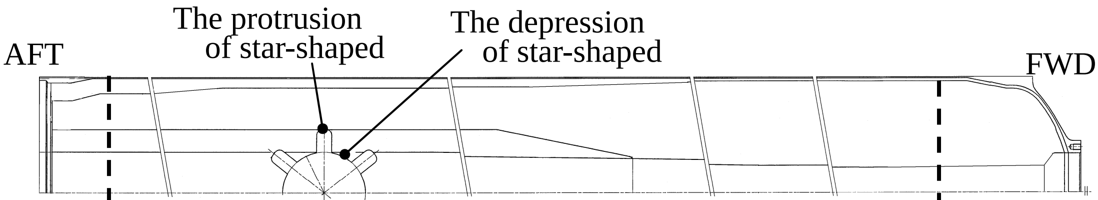

Fig. 15. Shape of S310 rocket motor

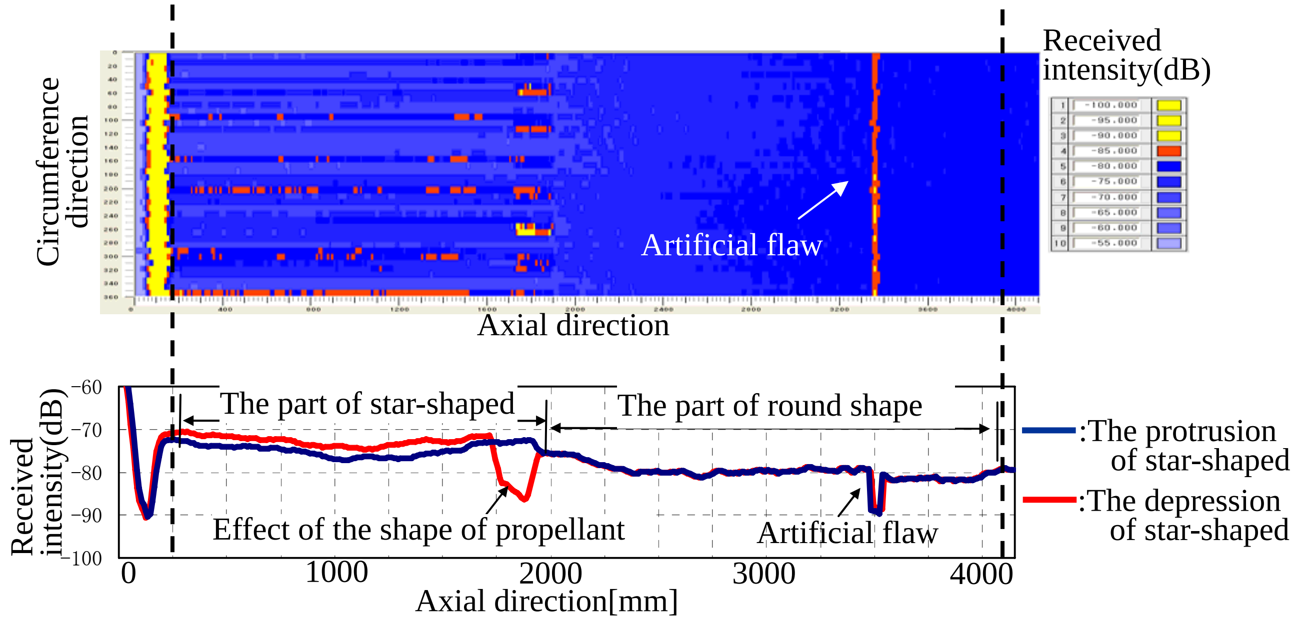

Fig. 16. Result of the inspection

Fig.16 shows the result of inspection. In the forward part, received intensity is approximately shown at a constant value. And in the after part, there are the protrusion and the depression of star-shaped. Each of star-shaped has different thickness of propellant, So received intensity is not constant. But in each of star-shaped, transition of received intensity is smooth and has no part of discontinuity. So, there are no flaws that exceed the acceptable size of flaw of S310.

4. SUMMARY

Applied ultrasonic detector by non contact method to production of"S310"SRM, we confirmed that there are no flaws which exceed the acceptable size of flaw of S310. And we developed inspection system that could scan automatically, which reduced the inspection time by about 40% compared with X ray inspection.

This system has a merit that we can inspect at the launch site, because the constrain of the inspection location is less than X ray inspection.

5. ISSUES FOR THE FUTURE

ⅰ. Confirmation for measuring the depth of flaws

In the non-contact method, there is a problem for measuring the depth of flaws. The depth of flaws can be detected by shifting transmitter like Fig.17 and obtaining a flat image like Fig.16. 1)

ⅱ. Improvement of received intensity

The inner surface of propellant is curved, which inflect ultrasonic like Fig.18. So, receiving intensity is reduced on the exterior surface of motor case. If this problem is improved, inspection time will be shorted by improvement of Signal-Noise ratio.

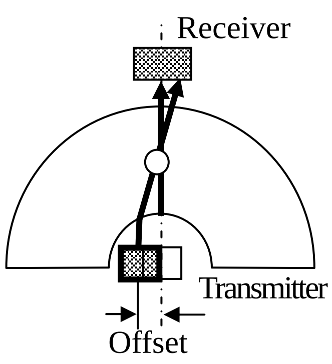

Fig.17. How to identify the depth of flaws[3]

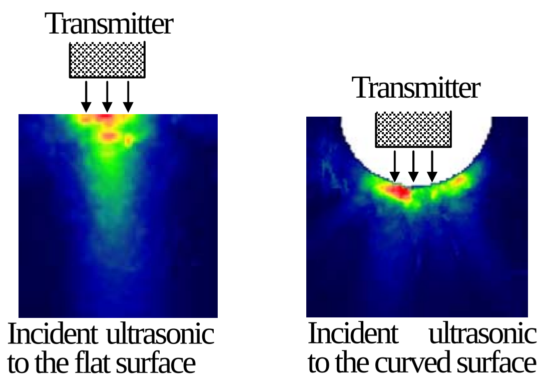

Fig.18. Intensity distribution of ultrasonic[4]

References

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2) Kiyotaka YAMASHITA, "Development of Non-Contact Ultrasonic Inspection System for the Sounding Rockets", The 11th Symposium on Nondestructive Evaluation for New Materials, pp.30-35