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AUTO-IDENTIFICATION FIBEROPTICAL SEAL VERIFIER

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Yoichi YAMAMOTO and Takehiro MUKAIYAMA

日本原子力研究所
Japan Atomic Energy Research Institute

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Auto-identification Fiberoptical Seal Verifier

Yoichi YAMAMOTO and Takehiko MUKAIYAMA+

Department of Fuel Cycle Safety Research
Nuclear Safety Research Center
Tokai Research Establishment
Japan Atomic Energy Research Institute
Tokai-mura, Naka-gun, Ibaraki-ken

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An auto COBRA seal verifier was developed by Japan Atomic Energy Research Institute (JAERI) to provide more efficient and simpler inspection measures for IAEA safeguards. The verifier is designed to provide means of a simple, quantitative and objective judgment on in-situ verification for the COBRA seal. The equipment is a portable unit with hand-held weight and size. It can be operated by battery or AC power. The verifier reads a COBRA seal signature by using a built-in CCD camera and carries out the signature comparison procedure automatically on digital basis. The result of signature comparison is given as a YES/NO answer. The production model of the verifier was completed in July 1996. The development was carried out in collaboration with Mitsubishi Heavy Industries, Ltd.

This report describes the design and functions of the COBRA seal verifier and the results of environmental and functional tests. The development of the COBRA seal verifier was carried out in the framework of Japan Support Programme for Agency Safeguards (JASPAS) as a project, JD-4 since 1981.

Keywords: Safeguards, COBRA seal, Verification, C/S (Containment and Surveillance), Inspection, JASPAS, IAEA

+ Center for Neutron Science

光ファイバー封印自動検認器

日本原子力研究所東海研究所安全性試験研究センター燃料サイクル安全工学部
山本　洋一・向山　武彦+

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日本原子力研究所は、IAEA 保障措置の査察効率向上のために光ファイバー封印検認器の開発を進めてきた。本検認器は、光ファイバー封印（コブラ封印）の現場検認において、より簡単で解析的な判定手法を提供するものである。

今回開発した検認器は、小型・軽量の携帯型装置で、バッテリーまたは AC 電源により動作する。装置内蔵の CCD カメラで読み取ったコブラ封印の光学パターンをデジタル処理して、パターン間の比較判定を行い、最終的な検認結果を表示する。1996 年 7 月に検認器の製品モデルが完成した。なお、本開発は、三菱重工業（株）の協力を得て実施された。

本報告書は、コブラ封印自動検認器の概要及び性能試験について述べたものである。なお、本研究は日本国の IAEA 保障措置支援計画(JASPAS)の一環として、1981 年よりプロジェクト JD-4 として実施してきたものである。

東海研究所：〒319-1195 茨城県那珂郡東海村白方白根 2-4
+ 中性子科学研究センター

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1. Introduction

A few ten thousands of metal cap seals (Type-E and Type-X seals) are in routine use by IAEA as a simple C/S (Containment and Surveillance) measure for safeguards. These seals are removed during an inspection visit and returned to the IAEA headquarters for verification. This process results in a delay in verification and resolution of anomalies. An "in-situ" verifiable seal eliminates this delay and provides timely information for the operator and the inspectors to resolve anomalies if any during an inspection visit. The in-situ verification also permits repeated use of the same seal without being removed for verification, and thus provides a considerable saving in effort as compared with that required for conventional sealing, sampling, replacement and subsequent verification at IAEA headquarters.

The COBRA seal was developed by the Sandia National Laboratories as an in-situ verifiable sealing system[1,3]. The system consists of a fiber optic loop with seal body and a seal signature recorder/verifier. The seal signature is photographed by the seal recorder/verifier. The verification by the photograph overlay comparison is an effective and accurate method under normal circumstances. However when the number of concerned seals is larger, the human eye/brain comparison will be faced with an ambiguous judgment. To solve this problem, development of a simpler and quantitative means for in-situ verification was desired.

Taking into consideration the appropriate features of the COBRA seal as a replacement for the Type-E seal, and the necessity of easier approaches to in-situ verification, development of the electronic verifier of the COBRA seal was started at JAERI[2]. This work has been carried out in the framework of Japan Support Programme for Agency Safeguards (JASPAS) as a project, JD-4 since 1981.

The verifier is designed to provide means of a simple, quantitative and objective judgment on in-situ verification for the COBRA seal. The equipment is a portable unit with hand-held weight and size. It can be operated by battery or through AC power. The verifier reads a COBRA seal signature by using a built-in CCD camera and carries out the signature comparison procedure automatically on digital basis. The result of signature comparison is given as a YES/NO answer.

2. COBRA Seal

2.1 COBRA Seal Description

The COBRA seal is a security seal which indicates unauthorized access to an area or equipment. It is designed to provide identity and integrity information by means of visual comparison of seal images with a reference image taken at the time of installation. Every seal body is identified with a unique serial number on the seal face.

The seal consists of a seal body which secures both ends of a fiber optic cable (Fig.1). The seal body is made of a clear plastic material for its tamper indicating feature. The external dimensions of the body are 5 x 2.5 x 1.6 cm. The fiber optic cable which forms the seal loop is made up of a jacketed bundle of 64 plastic fibers of diameter 0.254 mm (10 mil). And the outside diameter of the cable is 3.3 mm. The cable ends are secured in the seal body by means of two compression pins located on both side of a cutting blade. The serrated blade cuts approximately half of the optic fibers randomly in both ends of the cable. The fibers which have been cut will not transmit light, while those which have not been cut do transmit light. When the seal face is illuminated after the seal is installed, a unique random pattern of lit and unlit fibers is formed at the ends of the fiber optic cable. This unique pattern, which can be called seal signature, can then be verified by comparing the observed pattern of fibers with the initial reference pattern recorded at the time of applying the seal. Difference between the patterns indicates the possible tampering of the seal. Figure 2 shows an optical image of a COBRA seal signature.

The conventional verification method of COBRA seals is based on the inspector's visual comparison of photos of the signatures. This verification method requires inspector's subjective judgment and great concentration[4]. And it is a time consuming procedure when a large number of seals are involved.

2.2 Features of COBRA Seal Signature

Figure 3 shows a typical 3-D gray level distribution of a digitized image of a COBRA seal signature recorded with the CCD camera of the verifier. The gray level represents the transmitted light level through uncut fibers. The pixel-wise gray level distribution within one fiber is not uniform and tends to have higher values in the center area than in the peripheral area. The average gray level of individual fibers is not uniform due to nonuniformity of light illumination condition and to different surface condition of end face of fibers.

A digitized image of a seal signature is converted into a binary pattern image to make image processing easy. Each pixel is assigned to be one or zero when gray level of the pixel is higher than a threshold level or lower. Figure 4 shows the effect of the variation in threshold level on conversion a digitized seal image into a binary pattern image. Thus, a binary pattern image obtained by a fixed threshold level has threshold dependency because of the digitized seal image's features mentioned above. Therefore, it is not adequate to use a fixed threshold level to obtain a proper binary pattern image. The method to get a proper binary pattern image from an original CCD camera image will be discussed in Section 4.1.

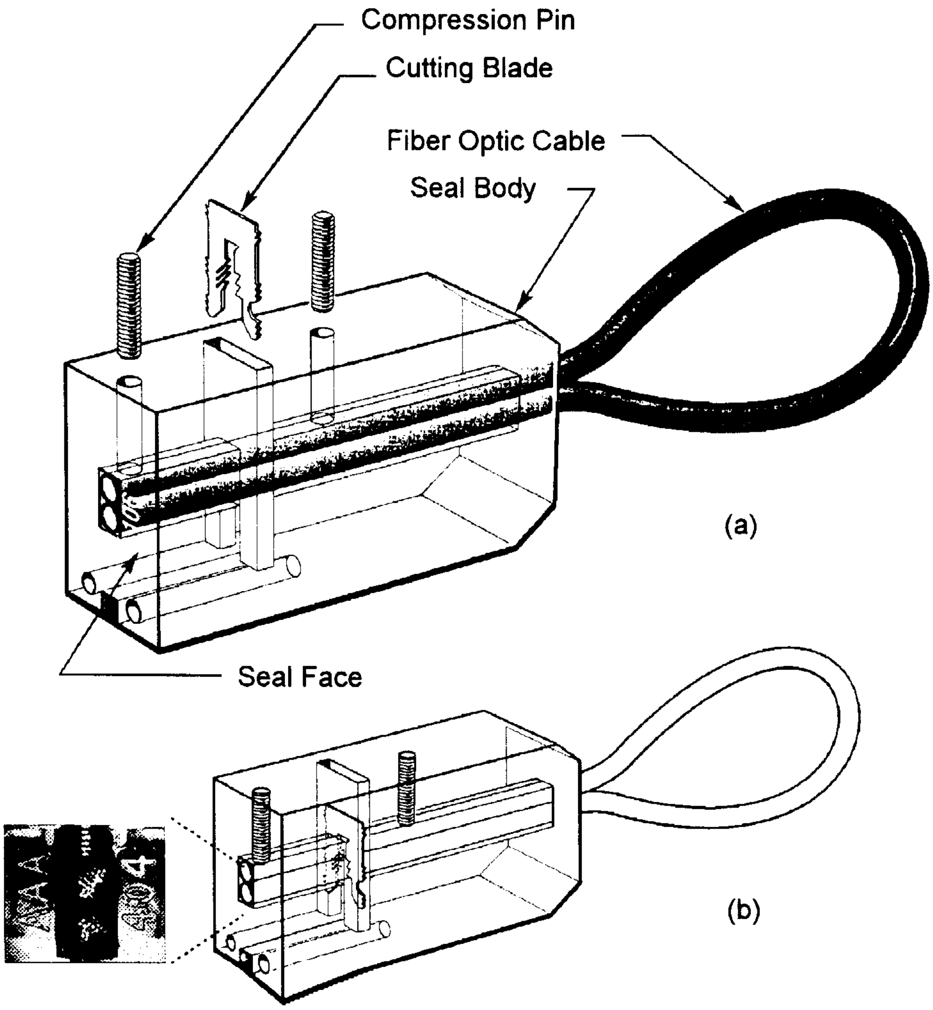


Fig. 1 COBRA seal assembly ((a) before installed, (b) after installed)

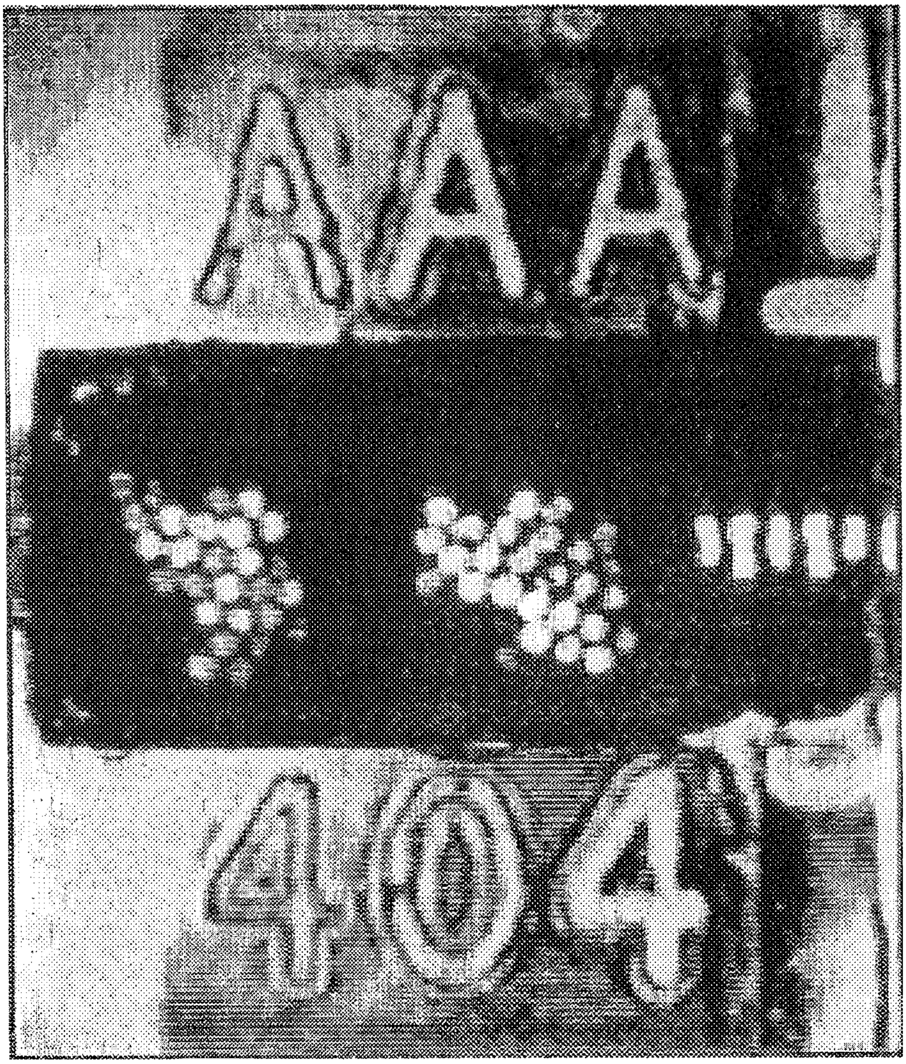


Fig. 2 An example of a COBRA seal signature recorded with a CCD camera

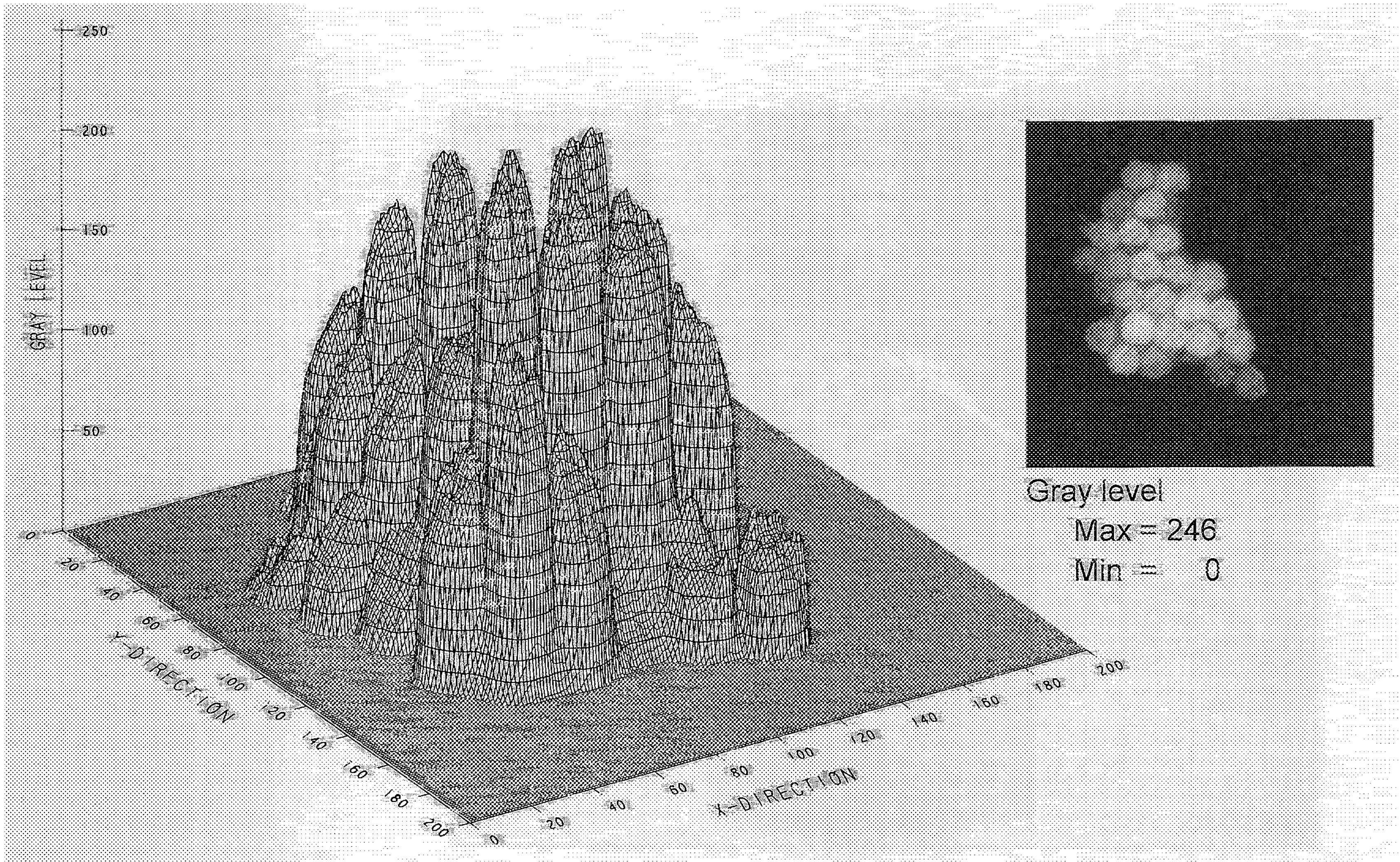
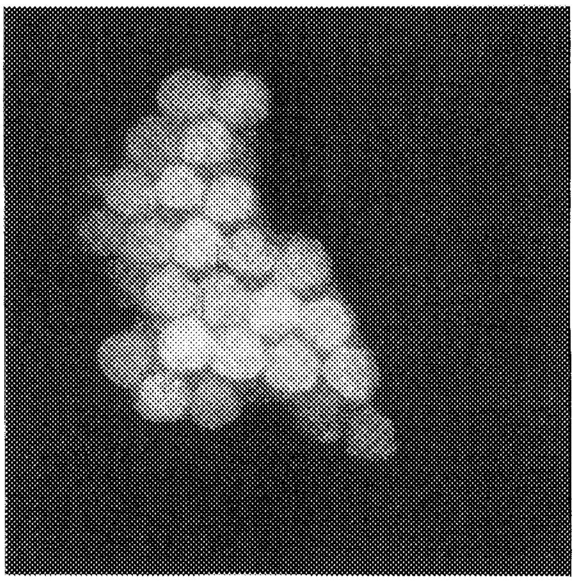
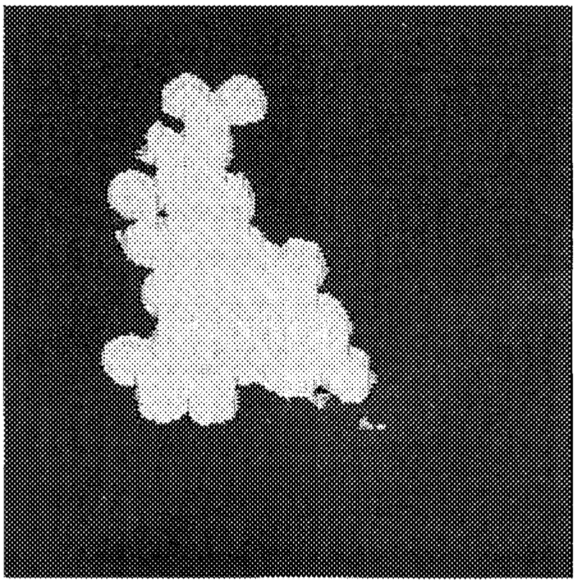


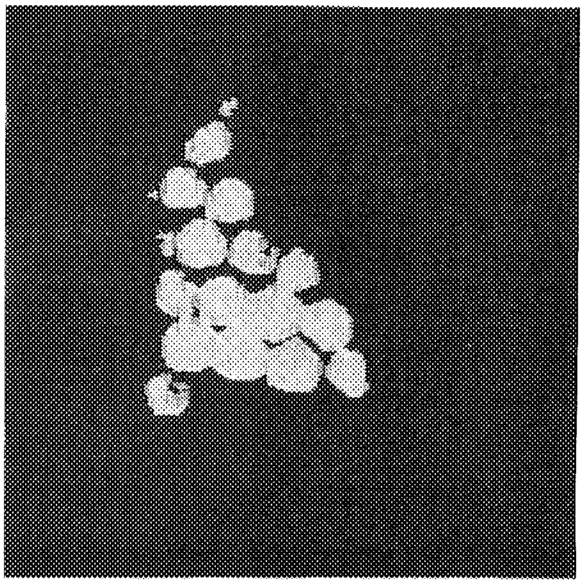
Fig. 3 Typical 3-D gray level distribution of transmitted light through uncut fibers



(a) A digitized image of a seal signature
(Gray level: 0-254)



(b) A binary pattern image
(Threshold level = 60)



(c) A binary pattern image
(Threshold level = 120)

Fig. 4 Effect of the variation in threshold level on binary image conversion

3. COBRA Seal Verifier

Considering the problem of the conventional verification method of the COBRA seal mentioned above, the design of the auto verifier is based on the following guidelines:

- In-situ verification of the COBRA seal,
- Simple and quantitative means,
- Digital image processing,
- Hand-held equipment,
- Battery operation,
- 50 seals verification capacity,
- Data exchange capability with other computer, and
- User friendly man-machine interface.

Development of a verifier using a new verification method was started by JAERI in collaboration with Mitsubishi Heavy Industries, Ltd. in 1990[5]. A prototype model of the verifier was completed in March 1995. The evaluation tests were performed by the IAEA in October 1995. The production model (Fig.5) which was modified to accommodate the IAEA comments based on its test results was completed in July 1996[7].

3.1 System Configuration

The verifier is one piece unit consisting of, 1) a seal insertion receptacle, 2) a system control circuit board with a central processing unit (CPU), 3) a liquid crystal display (LCD) panel, 4) some control keys and 5) a power supply module. The seal receptacle is composed of an optics system, a light emission diode (LED) for seal face illumination and a CCD (Charge Coupled Device) camera module.

A sketch of the verifier is shown in Fig.6. Figure 7 and Figure 8 show the block diagram and the CPU board of the verifier respectively.

A verifier unit consists of following items:

a) Seal receptacle
   Illumination source (LED; Light-emitting diode)
   Optical lens
   CCD camera (Monochrome, 512H x 480V pixels, NTSC video out)

b) System control
   CPU board (NEC V40HL 16MHz, Flash EPROM 512KB, S-RAM 512KB, Clock, etc.)

CCD control board

PC memory card control board

c) Display

LCD; Liquid crystal display (Monochrome, 192H x 192V pixels) with back light

d) Control keys

Cursor (Up, Down, Right, Left) keys, Command (Yes, No, Menu) keys and Help key

e) Power supply

Lithium-ion (Li^+) battery (DC7.2V, 1,350mAh) or,

AC power adapter (AC100~240V/DC7.2V, 2.0A)

f) External memory

PC memory card (S-RAM type, 256KB~4MB, in accordance with PCMCIA V2.1 and JEIDA V4.2 standard)

(1) Seal Receptacle

The seal receptacle is composed of a seal holder, an optics system, a light-emitting diode (LED) as a light source, and a CCD camera. The seal holder is designed to hold the COBRA seal body while an image is being taken of the seal signature. The seal holder has a micro-switch to detect seal insertion. After the sensor is switched on, the LED illuminates a seal face during the seal signature image is read.

(2) System control

The system control part is composed of the CPU board, the CCD control board and the PC memory card control board. The CPU board contains the central processing unit (CPU) and coordinates all function of the verifier. Time and date functions can be set on the verifier. As the system software is stored on the flash memory of the CPU board, the update of the software can be accomplished quickly. The CCD control board converts an analog image from the CCD camera into a digital image and stores the image on the image memory of the board. The digitized image is 160x110 pixels with 256 gray levels.

(3) LCD (Liquid Crystal Display)

The LCD displays seal signature images, verification results, command menu, information on instruction command, summary of seal data recorded in a PC memory card and system status.

(4) Control Keys

The verifier has eight control keys: four cursor keys, three command keys and help key. The user operates the system by selecting an instruction from a command menu by using cursor and command keys. Pressing the help key provides information about a command for the user.

(5) Battery

The verifier is operated by a lithium-ion battery. One of the merits of the battery is the indication of remaining energy level. 50 seals can be verified once a battery is fully charged. The battery is accessible through a battery door on the verifier unit case and can be charged from a 100-240VAC source.

(6) AC power adapter

The verifier is also operable from an external power source through an AC power adapter. The adapter is capable of automatic adaptation from 100 to 240 VAC, at a line frequency of 50 to 60Hz.

(7) PC memory card

A PC memory card is used as an external data storage medium of the verifier. Only static RAM cards are available for the verifier as the type of PC memory card. The verifier can handle a card with 256K-4Mbyte storage capacity. A 2Mbyte memory card can store 100 seal data; 50 seal data are for the reference and 50 for the verification. The verifier cannot format any PC memory card by itself to prevent data deletion by careless mis-operation. Therefore a new PC card has to be formatted by other PC before its usage.

3.2 Mechanism

When a seal body is inserted into the seal receptacle, an optical image of seal signature is read by the built-in CCD camera, and digitized on sampling basis. The seal ID is also read automatically at the time of seal insertion by using a pattern matching technique. The digitized image data of a COBRA seal signature consists of 160x110 pixels with 256 gray levels and is stored on the temporary image memory. The system recognizes each fiber in the seal signature image by using a pattern recognition technique. After the pattern recognition process, all center positions of individual fibers recognized are saved on a PC memory card as a part of seal data.

A seal data consists of a seal signature image and some information about inspection activity on a site and the results of pattern recognition/verification. The file size of each seal data is 20,480 bytes. The file name of a seal data is automatically generated by using the seal ID. The file name extension ".S" is used as the reference data* and ".V" as the verification data† respectively. When a seal signature is read and any file corresponding with the seal ID is not found on a PC card, the system stores the seal signature as the reference data. When a

* Reference data: the original image taken of a COBRA seal when installed

† Verification data: the image taken of a COBRA seal for verification purposes

corresponding file with the file extension ".S" is found, the system compares the signature with the reference data to verify the seal.

The reference seal data are compared with the verification data and a correlation coefficient between them is calculated. When a correlation coefficient is greater than a threshold level given for judgment, 'YES' is displayed on the LCD screen together with the correlation coefficient value. If not, 'NO' is displayed. In case of 'NO', the difference between the two signatures can be visually checked on the images displayed on the LCD screen.

3.3 Features

The verifier is one piece unit with a hand-held weight and size: about one kilogram in weight including a rechargeable battery, 120(W) x 200(L) x 55/45(H) mm in its external dimensions. The equipment is operated by a commercially available lithium-ion battery or an AC power (AC100~240V). A fully charged battery is capable of taking and verifying at least 50 seal images.

All verification functions except the printout of seal data can be performed by a verifier unit alone. Other computer is not required for in-situ seal verification. However, for PC card formatting, a computer is necessary.

Since all seal data are recorded on a PC memory card, the users are able to verify a large number of seals at once or print out the verification results by using the other computer. Up to 100 seal data can be stored on a 2MB PC card: 50 as the reference data and 50 as the data to be verified. All data in the verifier memory are protected by a back-up battery.

The verifier was developed as a device with user-friendly interface. The system provides a user friendly, menu driven interface for the users. Inspectors are asked to follow the procedures indicated on the LCD screen and they do not need to read any manual. The remaining capacity level of the battery will be indicated and an alarm for low level.

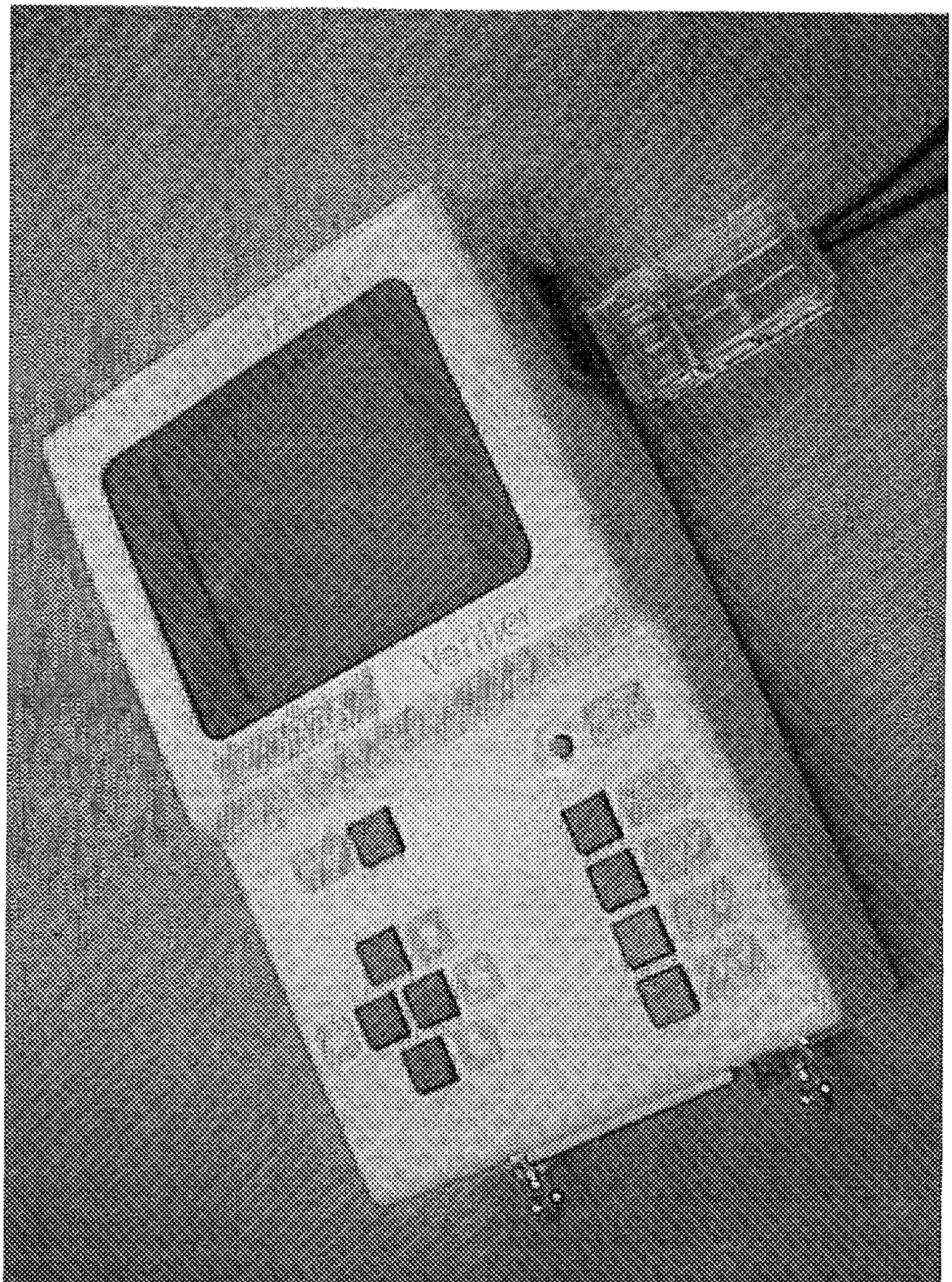
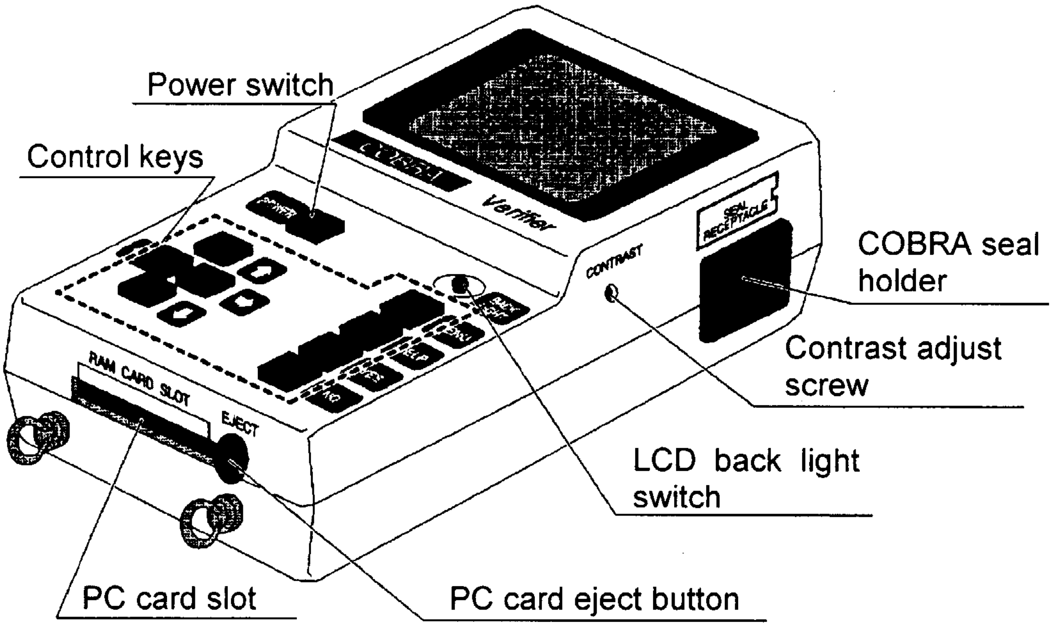
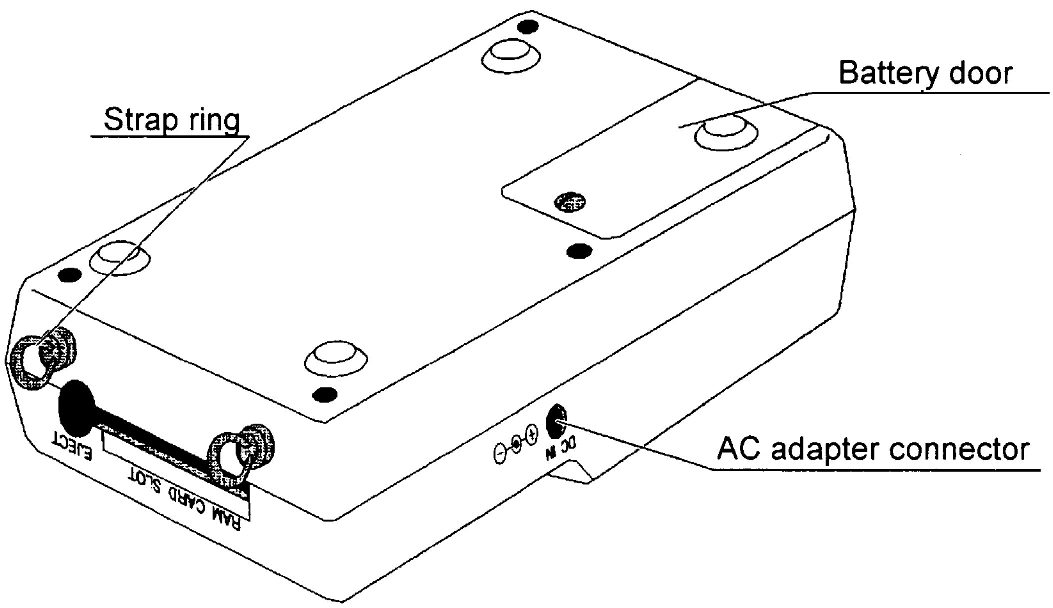


Fig. 5 COBRA seal verifier



(a) Front view



(b) Rear view

Fig. 6 Sketch of the COBRA seal verifier

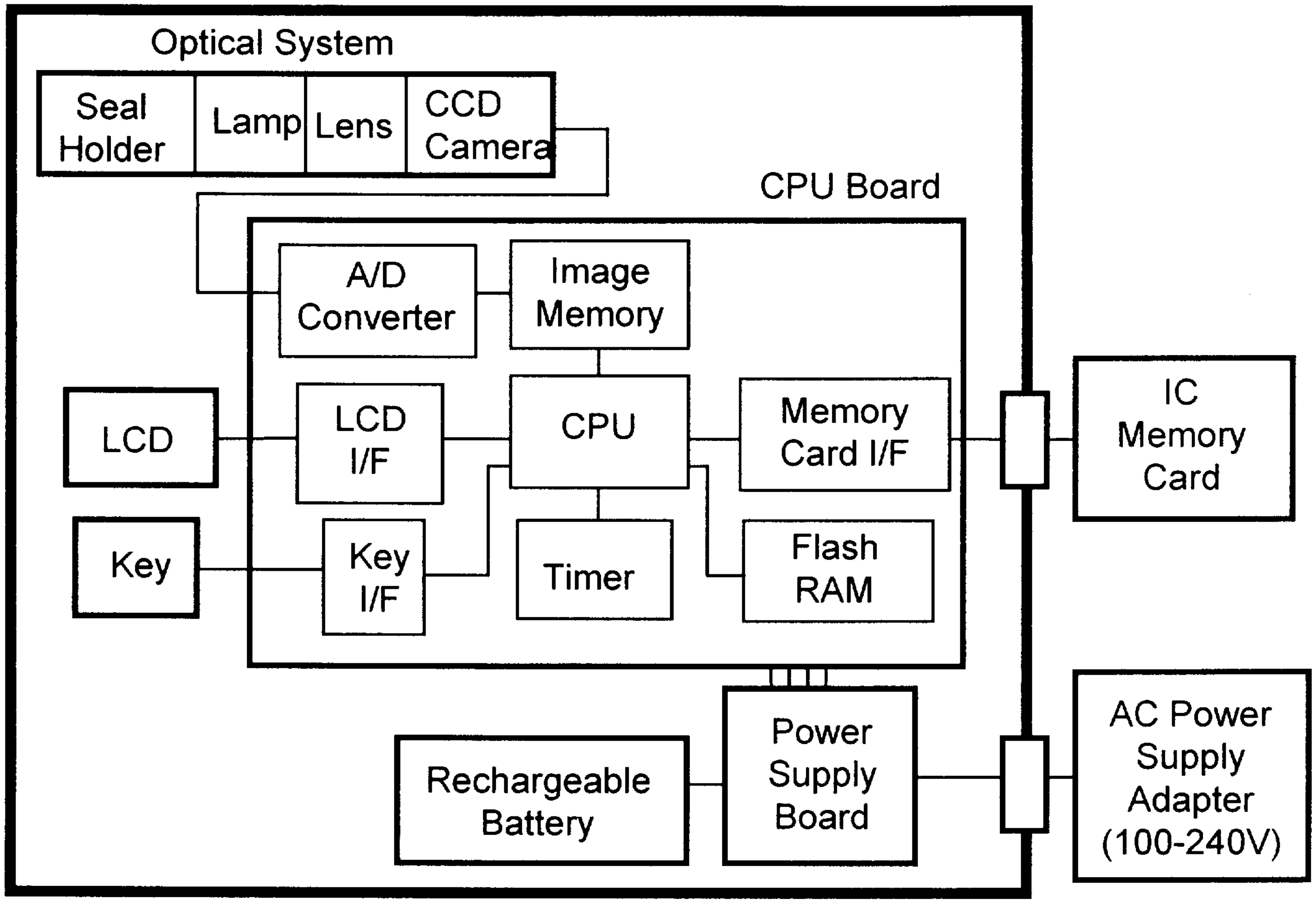


Fig. 7 Block diagram of the COBRA seal verifier system

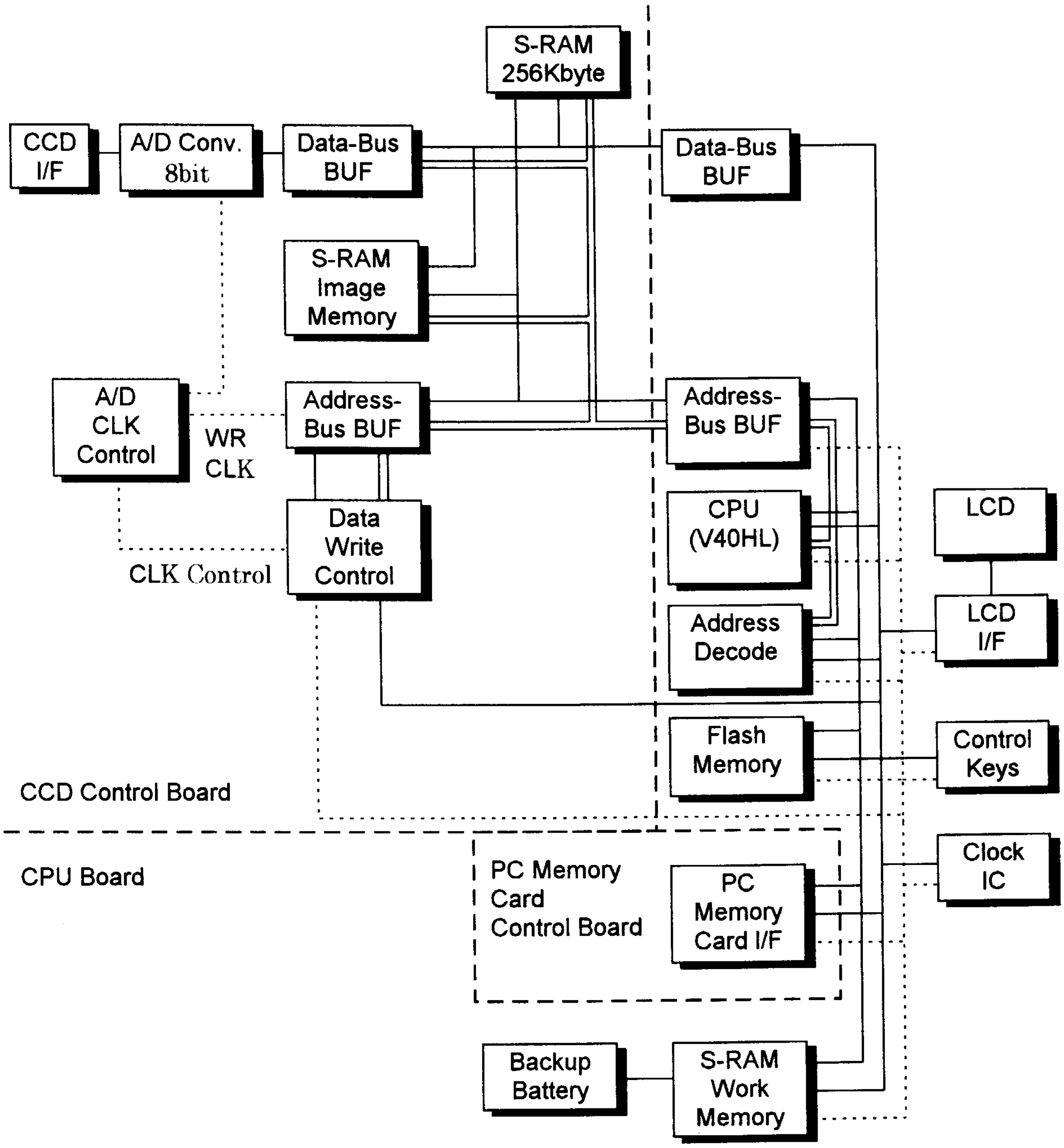


Fig. 8　Block diagram of system control board

4. Seal Verification Software

The seal verification software consists of two program modules, namely, a pattern recognition program and a program for seal integrity judgment. The main feature of the pattern recognition program is to obtain a binary pattern image of a seal signature and to calculate center coordinate of individual fibers in the binary image by using a pattern recognition technique. The program for seal integrity judgment gives YES/NO answers by using a correlation coefficient between an reference seal signature and a seal signature to be verified.

4.1 Pattern Recognition Program

The pattern recognition program uses a dynamic thresholding technique at the conversion process of a digitized image into a binary pattern image for keeping the original shape of a seal signature. A flowchart of the pattern recognition algorithm is shown in Fig.9.

Step-1: Reading of seal signature image (Fig.10 (a))

An optical image of a seal signature is read by the built-in CCD camera in the verifier, and digitized on sampling basis. The digitized image consists of 160(H)x110(V) pixels with 256 gray level (= 8 bit).

Step-2: Conversion of a digitized image to a binary pattern image (Fig.10 (b))

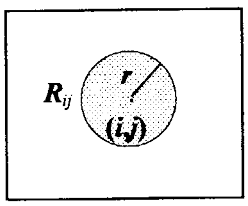
The digitized image which is consisted of gray level data for individual pixels is converted into a binary image by an adaptive thresholding process. Let $g(x,y)$ be an $M \times N$ pixel gray level image. Gray level $g(i,j)$ for a point (i,j) in the digitized image is compared with a dynamical threshold $T(i,j)$. The binarized value $h(i,j)$ for the same point after the thresholding process is defined as

$$h(i,j) = \begin{cases} 1 & \text{if } g(i,j) \geq T(i,j), \\ 0 & \text{if } g(i,j) < T(i,j). \end{cases} \qquad (4.1)$$

Here, we define the average gray level within a region R_{ij} for the point (i,j) as follow:

$$\bar{g}(i,j) = \frac{1}{n} \sum_{(x,y)\in R_{ij}} g(x,y) \qquad (4.2)$$

where R_{ij} is an inside area of a circle with its center at the point (i,j) and with a radius of r, n is the total number of pixels in R_{ij}.



Sg is the total average of gray level $g(i,j)$ over the hole area of the image, and is obtained as

$$Sg = \frac{1}{N} \sum_{(i,j)\in R_0} g(i,j) \qquad (4.3)$$

where R_0 is the whole area of the gray level image, N is the total number of pixels in R_0. Then, the threshold $T(i,j)$ is defined as follows,

$$T(i,j) = \begin{cases} \bar{g}(i,j) & \text{if } \bar{g}(i,j) \ge Sg, \\ Sg & \text{if } \bar{g}(i,j) < Sg. \end{cases} \tag{4.4}$$

Step-3: Decoupling of coupled fiber images in a binary pattern image

Some of binary images of fibers are coupled with other fibers as if a pair of dumbbells. As these connected images will give a wrong pattern recognition result, the coupled images shall be decoupled so as to be recognized properly as individual fibers. This process consists of two sub-steps.

Step-3-1: Integration of a binary pattern image (Fig.10 (c))

All points where $h(i,j) = 1$ in the binary pattern image obtained by Step-2 are changed to a new value $I(i,j)$ which is the integration of the area R_{ij}. The integrated value $I(i,j)$ is defined as follows,

$$I(i,j) = \sum_{(x,y)\in R_{ij}} h(x,y). \tag{4.5}$$

Step-3-2: Detection of maximum values of the integrated image(Fig.10 (d))

The integration value $I(i,j)$ is set to zero when the following condition is satisfied;

$$I(i,j) < I(k,l), \tag{4.6}$$

$$\text{where } \exists(k,l) \in R_{ij}.$$

As a result of this process, only groups of pixels with maximum values are remained and then represent central areas of individual uncut fibers.

Step-4: Labeling of individual fiber image

Every fiber image decoupled is labeled with its own number for discrimination.

Step-5: Calculation of center coordinates of fibers (Fig.10 (e))

Assuming that fiber cross section is a circle shape, the center coordinates (i_G, j_G) of each fiber is computed as the centroid coordinates of a decoupled fiber image obtained by Step-3. Let $f(x,y)$ be an $M \times N$ pixel binary image. The zeroth moment m_{00} and the first moment m_{10}, m_{01} of $f(x,y)$ are calculated respectively as follows,

$$\left.\begin{aligned} m_{00} &= \sum_{i=1}^{M}\sum_{j=1}^{N} f(i,j), \\ m_{10} &= \sum_{i=1}^{M}\sum_{j=1}^{N} if(i,j), \\ m_{01} &= \sum_{i=1}^{M}\sum_{j=1}^{N} jf(i,j). \end{aligned}\right\} \tag{4.7}$$

Then, the centroid coordinates (i_G, j_G) of the binary image $f(x,y)$ is defined as follows,

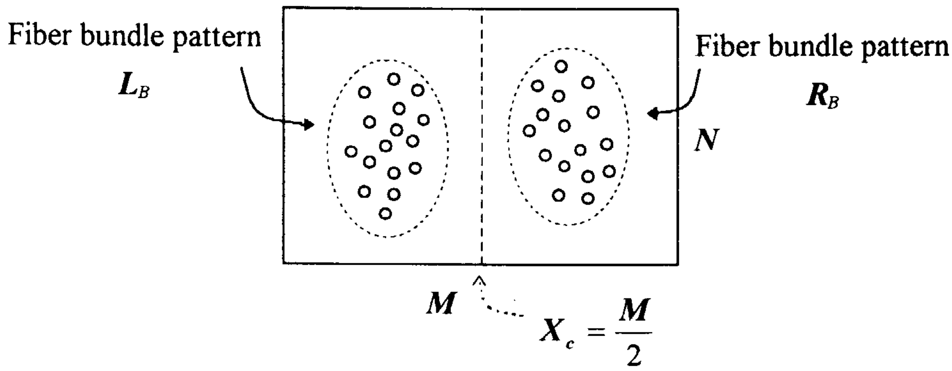
$$i_G = \frac{m_{10}}{m_{00}}, \quad j_G = \frac{m_{01}}{m_{00}}. \tag{4.8}$$

Step-6: Calculation of center coordinates of fiber bundle pattern

A seal signature is composed of two fiber bundle images of both ends of fiber optic cable. All center coordinates of fibers calculated in Step-5 are divided into two groups, L_B and R_B, by using their x coordinates as follows:

$$(i_n, j_n) \in L_B \quad \text{if } i_n < X_c,$$
$$(i_n, j_n) \in R_B \quad \text{if } i_n > X_c,$$

where (i_n, j_n) is the center coordinates of the n-th fiber, X_c is half of image width M.



Then, the center coordinates of each of fiber bundle pattern is calculated. The center coordinates (i_{BG}, j_{BG}) is defined as

$$i_{BG} = \frac{1}{N_f}\sum_{n=1}^{N_f} i_{Gn}, \quad j_{BG} = \frac{1}{N_f}\sum_{n=1}^{N_f} j_{Gn}, \tag{4.9}$$

where (i_{Gn}, j_{Gn}) is the center coordinates of the n-th fiber in a fiber bundle pattern, N_f is the total number of fibers in the fiber bundle pattern.

Step-7: Storing of fiber position data

After Step-6, all fiber position data computed in Step-5 and -6 are saved on an PC memory card with the image data and inspection activity information.

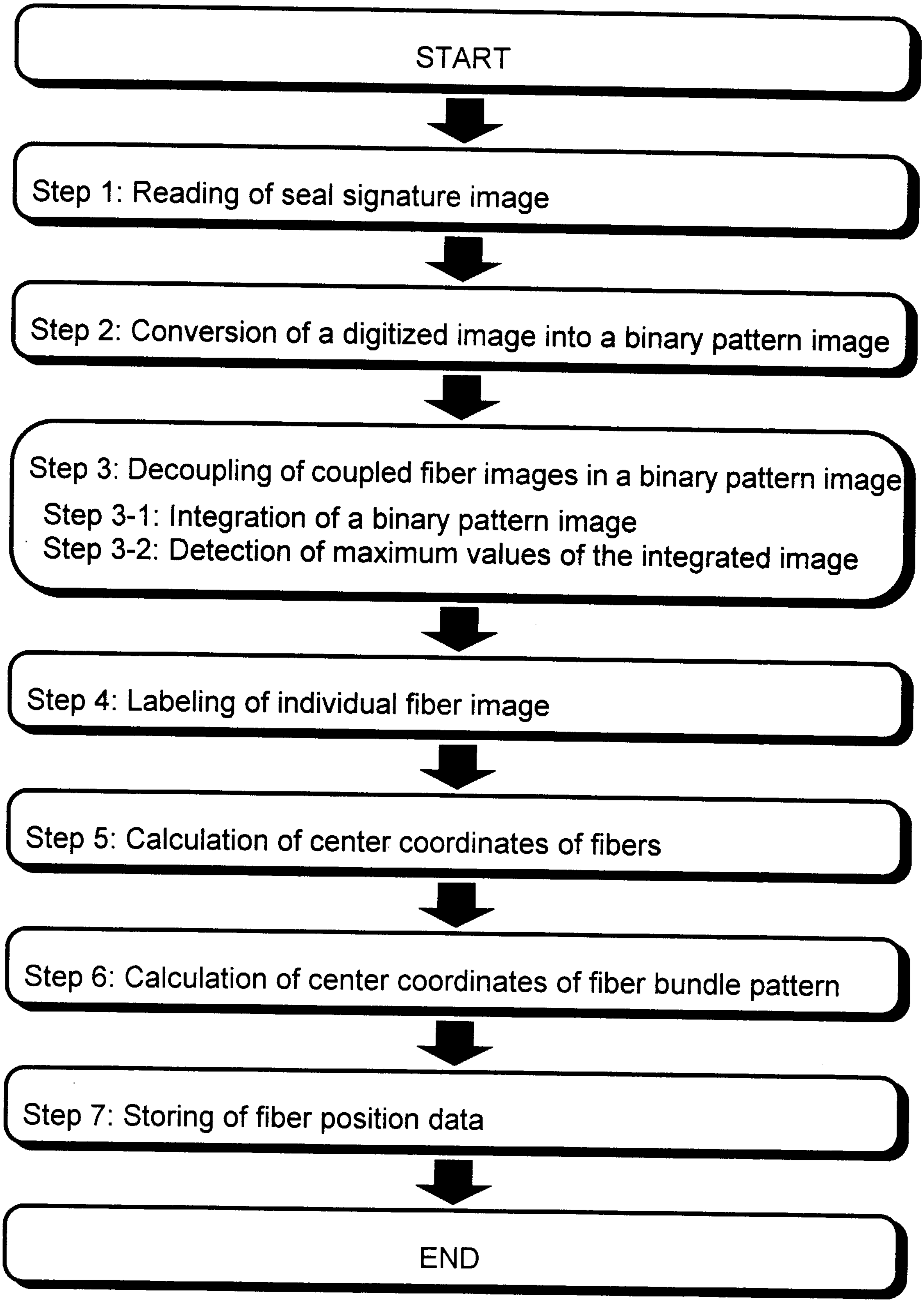
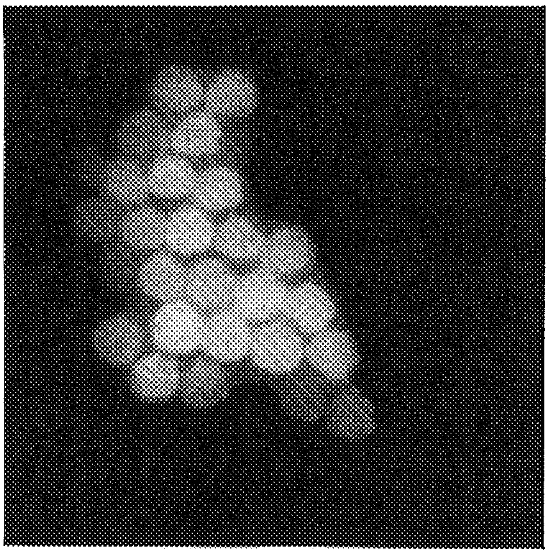
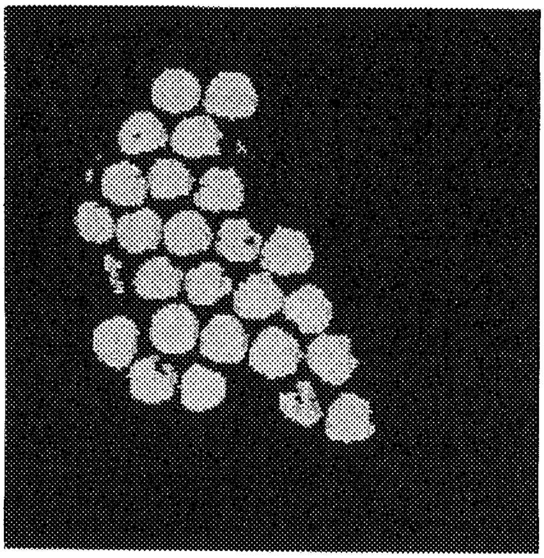


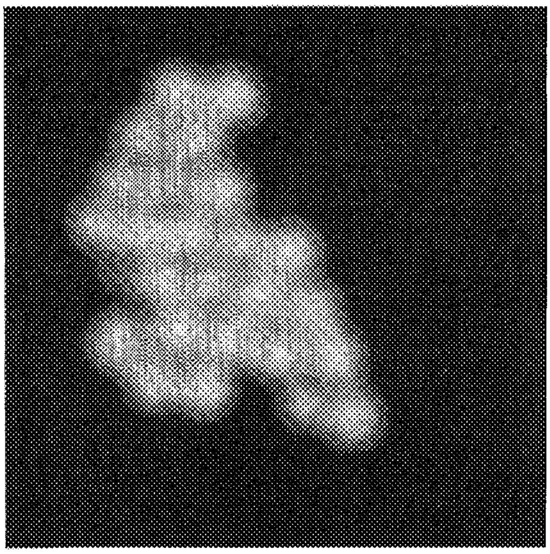
Fig. 9 Flowchart of pattern recognition algorithm



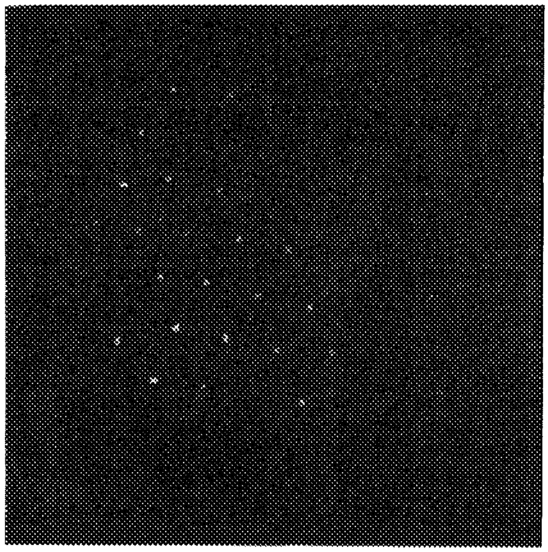
(a)



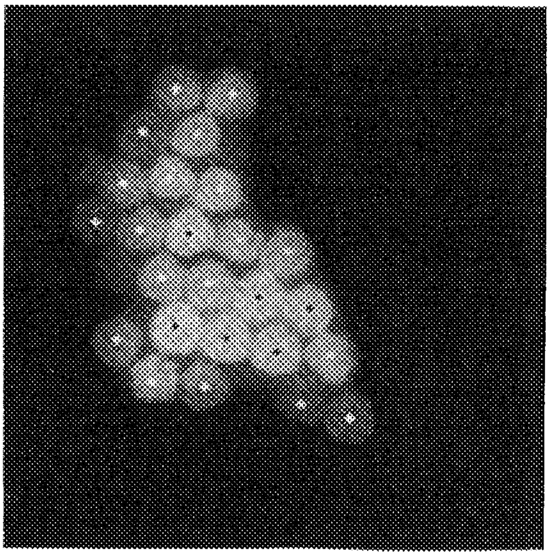
(b)



(c)



(d)



(e)

(a) A digitized image of a COBRA seal signature

(b) A binary pattern image

(c) An integrated iamge of Fig.10 (b)

(d) Detection of maximum integral values in Fig.10 (c)

(e) Detection of center position of each fiber

Fig. 10 Pattern recognition process

4.2 Program for Seal Integrity Judgment

After the pattern recognition process is completed, a correlation coefficient is calculated between the reference seal data [A] and the verification data [B]. The system makes a seal integrity judgment by comparing the correlation coefficient with a threshold value. Figure 11 shows a flowchart of the seal integrity judgment algorithm.

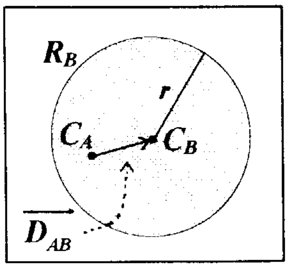
Step-1: Position adjustment of bundle centers for correlation coefficient calculation

The position of a seal signature image detected with a CCD sensor varies slightly due to the mechanical looseness of a seal receptacle and a seal body. To avoid this uncertainty, the center position will be slightly changed to match a seal image of a reference to that of a seal image to be verified.

Step-1-1: Calculation of vector between center positions

C_A and C_B are a center coordinates of a fiber in the reference data [A] and in the verification data [B] respectively. Let $\boldsymbol{R_B}$ be a whole region inside a circle with its center at C_B and with a radius of $\boldsymbol{r}$. When C_A is inside of the region $\boldsymbol{R_B}$, a vector $\overrightarrow{D_{AB}}$ directed from C_A to C_B is calculated.

The above process is repeated for all center coordinates in [A].

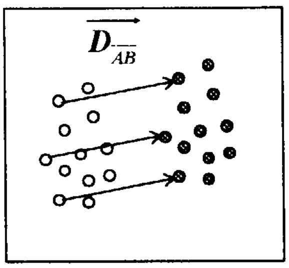


Step-1-2: Calculation of mean vector

A mean vector $\overrightarrow{D_{\overline{AB}}}$ is calculated from all vector obtained in Step-1-1.

Step-1-3: Shift of reference image by using mean vector

All center coordinates of the reference image [A] are shifted by the mean vector $\overrightarrow{D_{\overline{AB}}}$.



Step-1-4: Calculation of correlation coefficient (Fig. 12)

A correlation coefficient is calculated between the reference data [A] and the verification data [B]. The correlation coefficient Vc is defined as follows,

$$Vc = \frac{S}{Ni + Nn - S} \tag{4.10}$$

where

Ni : number of uncut fibers in the reference seal signature

Nn : number of uncut fibers in the seal signature recorded during each inspection visit

S : number of uncut fibers of which center position matches between the reference and newly taken signature within tolerance of a fiber diameter

Step-2: Detection of maximum correlation coefficient

Let Vc obtained at the first adjustment trial be Vc_{Max}. All center coordinates of the data [A] are shifted by a given pixel length. Then the procedures from Step-1-1 to Step-1-4 are repeated and a new correlation coefficient Vc_{Temp} is calculated. When Vc_{Temp} is greater than the current Vc_{Max}, Vc_{Max} is replaced by Vc_{Temp}. The given shift is ($\pm L, \pm 2L, \pm 3L, \pm 4L, \pm 5L$) pixel length along x and/or y axis from the original location.

The position adjustment will be repeated until the maximum correlation coefficient Vc_{Max} between [A] and [B] is obtained.

Step-3: Seal integrity judgment

Let Tj be a threshold to judge whether a seal is intact or not. The integrity of a seal is decided as follows:

If $Vc_{Max} > Tj$, the seal is intact.

If $Vc_{Max} \le Tj$, the seal may be tampered.

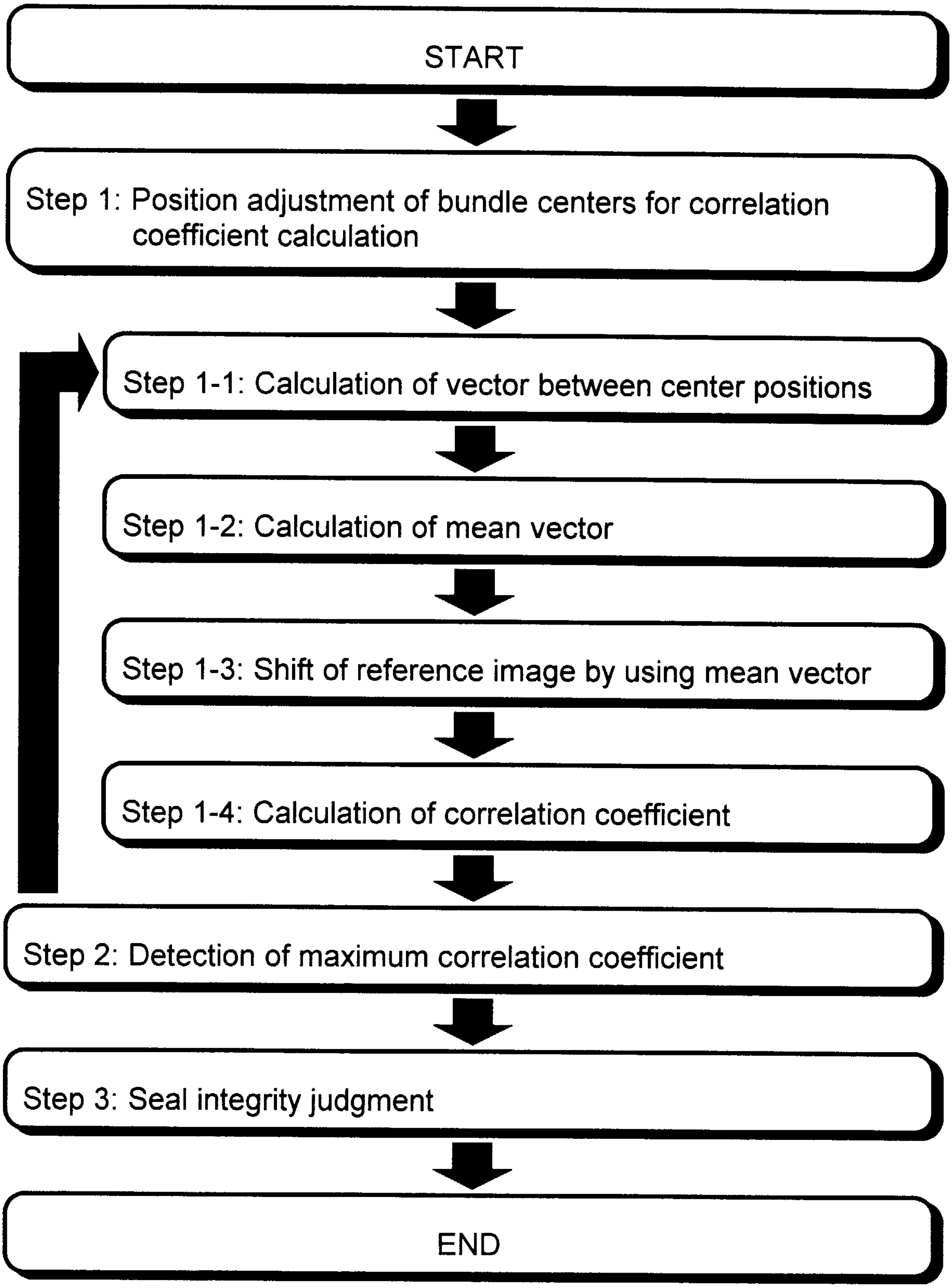
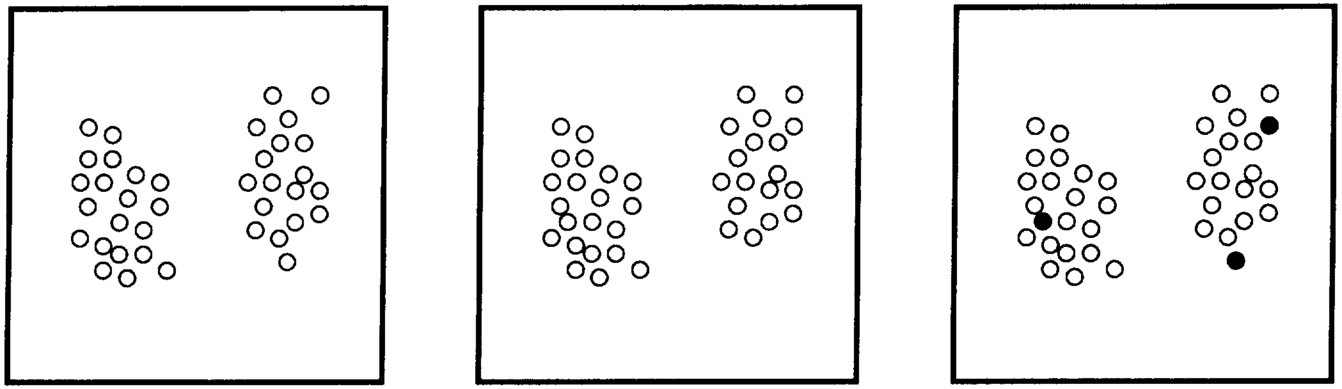


Fig. 11 Flowchart of seal integrity judgment algorithm



[A] Reference Seal Signature

[B] Seal Signature recorded during Inspection Visit

[C] Difference between [A] and [B]

Correlation Coefficient Vc

$$Vc = \frac{S}{Ni + Nn - S}$$

where

Ni : number of fibers in [A]

Nn : number of fibers in [B]

S : number of fibers of which center position matches between [A] and [B]

Fig. 12 COBRA seal verification method

5. Tests and Evaluations

5.1 Functional Tests

About 10 seconds is required to read a seal signature and store the data as the reference data on a PC memory card, while the total time required to read and verify a signature is approximately 15 to 20 seconds.

The reliability of seal ID recognition is higher than 90%, if the ID engraving on a seal face is very clear. Since a simple pattern matching technique is used for the ID recognition, the reliability decreases if seal ID characters are blurred.

Two verifier units were used for recording signatures of 25 seals with 1 m cable length. Each signature was read twice and correlation coefficients of every possible combination of these seals were calculated by the other computer. Figure 13 shows a histogram of correlation coefficients for repeated comparisons of the same seal and between the different seals. The repeated comparisons of the same seal (auto-correlation) are highly correlated (0.75~1.00), while those of the different seals (cross-correlation) show lower correlation (0.20~0.55). The gap between auto- and cross-correlation coefficients is large enough for the definite verification judgment.

5.2 Test for Battery Operation

The purpose of the test was to examine whether the verifier can verify 50 seals with a fully charged battery. Two of the six verifier units manufactured were selected at random and the number of seal verified by using them was counted. The test demonstrated that 70 and 68 seals were able to be verified with a fully charged battery. The function of low battery alarm was also confirmed during the same test.

5.3 Environmental Tests

The environmental tests of the verifier given in Table 1 was carried out in accordance with IAEA STR284 guidelines[6]. Some tests were performed in accordance with JIS (Japanese Industrial Standard). One verifier unit was used in these tests. A visual check and functional test of the verifier was also performed following the completion of each of the environmental tests.

No failure and hardware trouble was observed after the environmental tests.

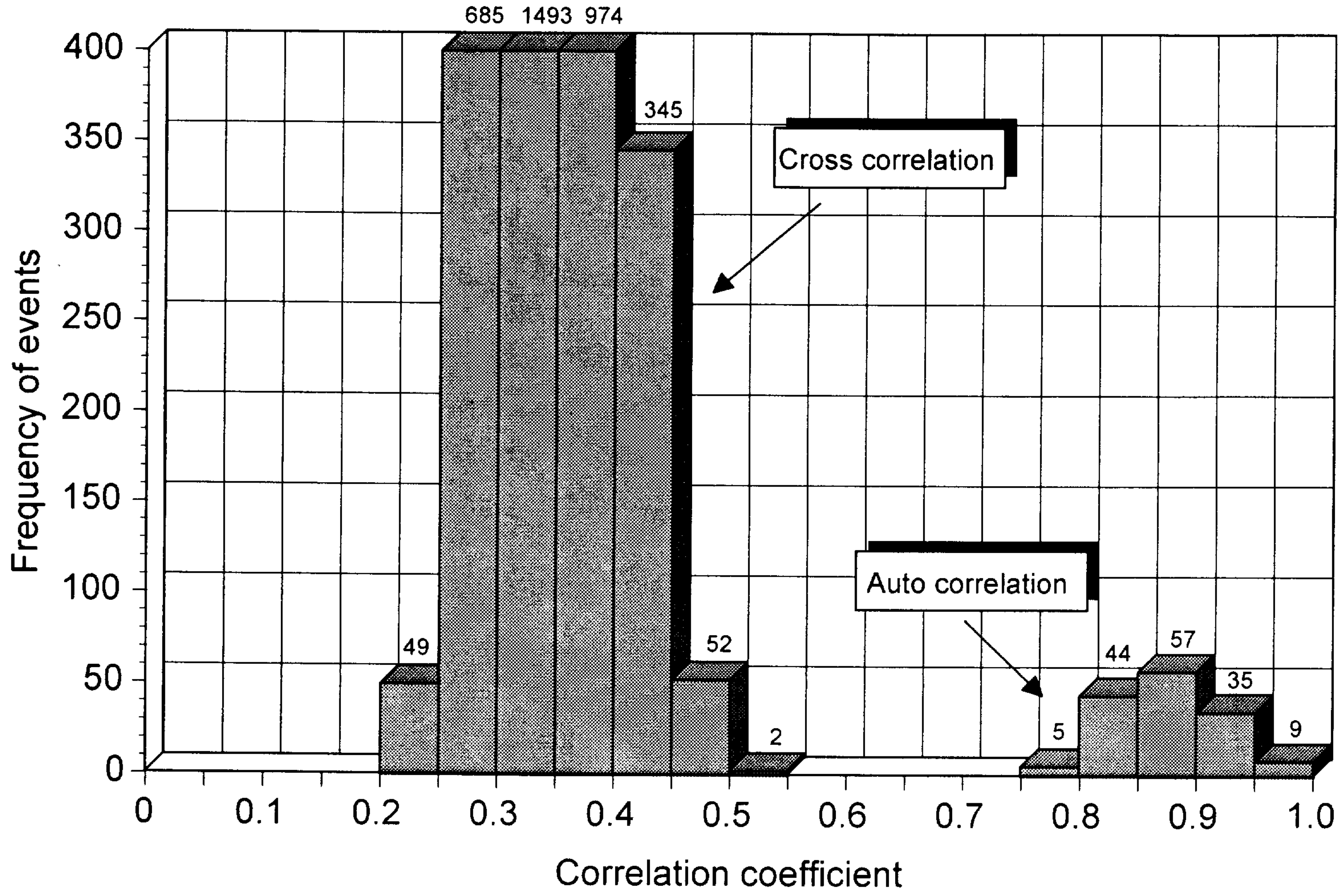


Fig. 13 Distribution of correlation coefficients obtained by repeated comparisons of 25 COBRA seal signatures measured by using two verifier units

Table 1 Environmental tests of the COBRA seal verifier

1	**Temperature/Humidity test (Fig.14)** One verifier unit was placed in an environment chamber and subjected to a temperature/ humidity test under the following conditions.
1)	**Temperature** The temperature was varied between 5 °C and 45 °C over a 15 day period.
2)	**Humidity** The humidity was held at 30% relative during the first half of the test period. Then it raised up to 90% relative and kept at this level for the latter half of the test period, while the temperature was varied between 5°C and 45°C to determine what condition cause condensation problems. At the final stage of the above test, the verifier unit was exposed to an environment of 0°C and 45°C for 24 hours respectively.
2	**Mechanical shock test**
1)	**Impact test** One verifier unit was packed in the carrying case. Then the case was mounted to a testing machine. A total of three shock pulses were applied for each of six axes. The shock pulse was a half-sine wave of 11±2ms duration with its acceleration peak at 6G.
2)	**Drop test** One verifier unit was packed in the carrying case. The case was dropped onto a concrete surface from a height of 18 inches kept one of its corners to the bottom. Similarly it was dropped while holding each of three sides adjacent to the corner to the bottom.

Table 1 Environmental tests of the COBRA seal verifier (continued)

3	**Vibration test** One verifier unit, packed in the carrying case, was mounted to a vibration fixture and subjected to the following vibration forces:
1)	**Truck transport (random wave)** Spectral density: $10e^{-4}$ to $0.015 (G^2/Hz)$ Vibration frequency: 10Hz to 3KHz 1.58RMS-G overall This test was performed for three hours in each axis.
2)	**Cargo air transport (random wave)**
a)	take-off & climb Spectral density: $10e^{-3}$ to $0.2 (G^2/Hz)$ Vibration frequency: 10Hz to 2KHz 9.9RMS-G overall This test was performed for five minutes in each axis.
b)	cruise Spectral density: $10e^{-5}$ to $0.015 (G^2/Hz)$ Vibration frequency: 10Hz to 2KHz 3.5RMS-G overall This test was performed for one hour in each axis.
3)	**Helicopter transport (sine wave)** Overall amplitude: ≤ 2.54mm Vibration frequency: 5Hz to 2KHz This test was performed for twenty minutes in each axis.
4	**Electrostatic noise test** Static electricity was applied to a verifier unit under operation by a electrostatic tester. The test conditions were as follows: Condenser capacity: 500pF Discharge resistance: 500Ω Applied voltage: +10KV and -10KV

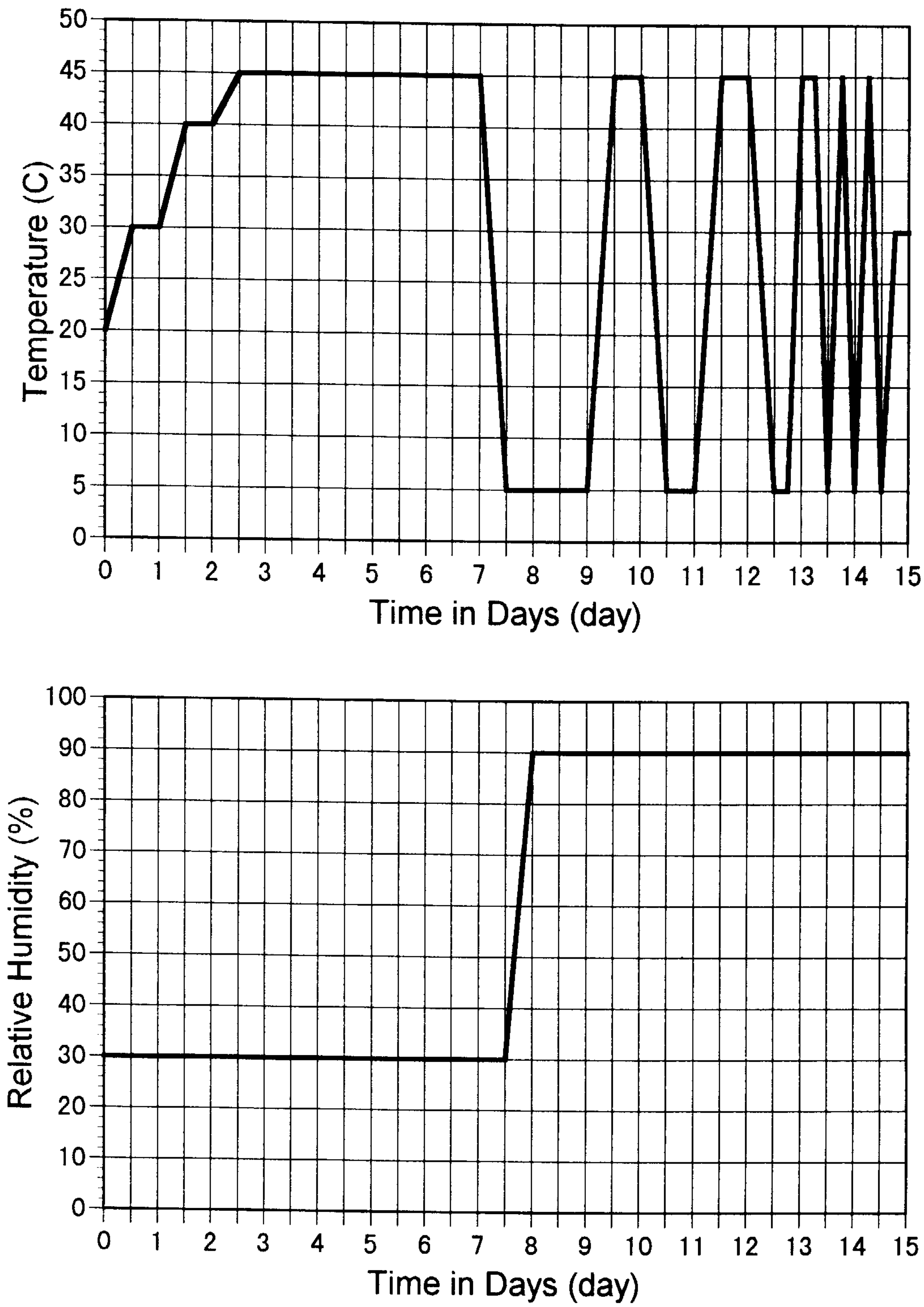


Fig. 14 Time schedule of the Temperature/Humidity test

6. Concluding Remarks

Japan Atomic Energy Research Institute (JAERI) developed an AutoCOBRA verifier to provide more efficient inspection measures for the IAEA safeguards in collaboration with Mitsubishi Heavy Industries, Ltd.. The verifier is designed to provide means of a simple, quantitative and objective judgment on in-situ verification for the COBRA seal. The equipment is a hand carry unit of weight and size. It is operated by battery or an AC power. The verifier reads a COBRA seal signature with a CCD camera and proceeds the signature comparison on digital basis. A final judgment is given as a YES/NO answer.

The experimental results have confirmed that the verifier performs reliable verification by using a pattern recognition technique and provides an unambiguous quantitative means in-situ verification of the COBRA seal. The IAEA decided to accept the verifier as an inspection equipment for general use in November 1995. The production model which was modified to accommodate the IAEA comments based on its test results was completed in July 1996. The first 12 units were delivered to the IAEA in January 1997.

The inspector's task for COBRA seal verification at an inspection site will be greatly simplified and completed quickly by using the AutoCOBRA verifier.

Acknowledgment

The authors gratefully acknowledge the significant contributions made by Mitsubishi Heavy Industries, LTD. for the development of the AutoCOBRA verifier. Special thanks are due to Mr. M. Goldfarb, Mr. R.Tzolov and Mr. V.Fortakov of IAEA for their valuable discussions. This work has been performed within the framework of the Japan Support Programme for Agency Safeguards (JASPAS).

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国際単位系 (SI) と換算表

表1　SI基本単位および補助単位

量	名　称	記　号
長さ	メートル	m
質量	キログラム	kg
時間	秒	s
電流	アンペア	A
熱力学温度	ケルビン	K
物質量	モル	mol
光度	カンデラ	cd
平面角	ラジアン	rad
立体角	ステラジアン	sr

表2　SIと併用される単位

名　称	記　号
分，時，日	min，h，d
度，分，秒	°，′，″
リットル	l，L
トン	t
電子ボルト	eV
原子質量単位	u

1 eV = 1.60218×10^{-19} J

1 u = 1.66054×10^{-27} kg

表5　SI接頭語

倍数	接頭語	記　号
10^{18}	エクサ	E
10^{15}	ペタ	P
10^{12}	テラ	T
10^{9}	ギガ	G
10^{6}	メガ	M
10^{3}	キロ	k
10^{2}	ヘクト	h
10^{1}	デカ	da
10^{-1}	デシ	d
10^{-2}	センチ	c
10^{-3}	ミリ	m
10^{-6}	マイクロ	μ
10^{-9}	ナノ	n
10^{-12}	ピコ	p
10^{-15}	フェムト	f
10^{-18}	アト	a

表3　固有の名称をもつSI組立単位

量	名　称	記号	他のSI単位による表現
周波数	ヘルツ	Hz	s^{-1}
力	ニュートン	N	$m \cdot kg/s^2$
圧力，応力	パスカル	Pa	N/m^2
エネルギー，仕事，熱量	ジュール	J	N·m
工率，放射束	ワット	W	J/s
電気量，電荷	クーロン	C	A·s
電位，電圧，起電力	ボルト	V	W/A
静電容量	ファラド	F	C/V
電気抵抗	オーム	Ω	V/A
コンダクタンス	ジーメンス	S	A/V
磁束	ウェーバ	Wb	V·s
磁束密度	テスラ	T	Wb/m^2
インダクタンス	ヘンリー	H	Wb/A
セルシウス温度	セルシウス度	℃	
光束	ルーメン	lm	cd·sr
照度	ルクス	lx	lm/m^2
放射能	ベクレル	Bq	s^{-1}
吸収線量	グレイ	Gy	J/kg
線量当量	シーベルト	Sv	J/kg

表4　SIと共に暫定的に維持される単位

名　称	記　号
オングストローム	Å
バーン	b
バール	bar
ガル	Gal
キュリー	Ci
レントゲン	R
ラド	rad
レム	rem

1 Å = 0.1 nm = 10^{-10} m

1 b = 100 fm^2 = 10^{-28} m^2

1 bar = 0.1 MPa = 10^5 Pa

1 Gal = 1 cm/s^2 = 10^{-2} m/s^2

1 Ci = 3.7×10^{10} Bq

1 R = 2.58×10^{-4} C/kg

1 rad = 1 cGy = 10^{-2} Gy

1 rem = 1 cSv = 10^{-2} Sv

（注）

1. 表1－5は「国際単位系」第5版，国際度量衡局 1985年刊行による。ただし，1 eVおよび1 uの値はCODATAの1986年推奨値によった。
2. 表4には海里，ノット，アール，ヘクタールも含まれているが日常の単位なのでここでは省略した。
3. barは，JISでは流体の圧力を表わす場合に限り表2のカテゴリーに分類されている。
4. EC閣僚理事会指令ではbar，barnおよび「血圧の単位」mmHgを表2のカテゴリーに入れている。

換　算　表

力	N(=10^5dyn)	kgf	lbf
	1	0.101972	0.224809
	9.80665	1	2.20462
	4.44822	0.453592	1

粘　度　1 Pa·s($N \cdot s/m^2$) = 10 P(ポアズ)(g/(cm·s))

動粘度　1 m^2/s = 10^4St(ストークス)(cm^2/s)

圧力	MPa(=10 bar)	kgf/cm^2	atm	mmHg(Torr)	lbf/in^2(psi)
	1	10.1972	9.86923	7.50062×10^3	145.038
	0.0980665	1	0.967841	735.559	14.2233
	0.101325	1.03323	1	760	14.6959
	1.33322×10^{-4}	1.35951×10^{-3}	1.31579×10^{-3}	1	1.93368×10^{-2}
	6.89476×10^{-3}	7.03070×10^{-2}	6.80460×10^{-2}	51.7149	1

エネルギー・仕事・熱量	J(=10^7erg)	kgf·m	kW·h	cal(計量法)	Btu	ft·lbf	eV
	1	0.101972	2.77778×10^{-7}	0.238889	9.47813×10^{-4}	0.737562	6.24150×10^{18}
	9.80665	1	2.72407×10^{-6}	2.34270	9.29487×10^{-3}	7.23301	6.12082×10^{19}
	3.6×10^6	3.67098×10^5	1	8.59999×10^5	3412.13	2.65522×10^6	2.24694×10^{25}
	4.18605	0.426858	1.16279×10^{-6}	1	3.96759×10^{-3}	3.08747	2.61272×10^{19}
	1055.06	107.586	2.93072×10^{-4}	252.042	1	778.172	6.58515×10^{21}
	1.35582	0.138255	3.76616×10^{-7}	0.323890	1.28506×10^{-3}	1	8.46233×10^{18}
	1.60218×10^{-19}	1.63377×10^{-20}	4.45050×10^{-26}	3.82743×10^{-20}	1.51857×10^{-22}	1.18171×10^{-19}	1

1 cal = 4.18605 J（計量法）

= 4.184 J　（熱化学）

= 4.1855 J（15 °C）

= 4.1868 J（国際蒸気表）

仕事率　1 PS（仏馬力）

= 75 kgf·m/s

= 735.499 W

放射能	Bq	Ci
	1	2.70270×10^{-11}
	3.7×10^{10}	1

吸収線量	Gy	rad
	1	100
	0.01	1

照射線量	C/kg	R
	1	3876
	2.58×10^{-4}	1

線量当量	Sv	rem
	1	100
	0.01	1

（86年12月26日現在）

Auto-identification Fiberoptical Seal Verifier