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# STUDY ON ELEMENTS TECHNOLOGY FOR AUTOMATION OF EXTERIOR WALL SEALING WORK

Teruo Yamamiya,[*1] Masahito Mori[*] and Shinji Yoshida[*3]

*1 Technology Research Center, Taisei Corporation
344-1 Nase-Machi, Totsuka-ku, Yokohama, Japan
*2 Technology Development Department, Taisei Corporation
1-25-1 Nishi-Shinjuku, Shinjuku-ku, Tokyo, Japan
*3 Tsuchiura Works, Hitachi Ltd.
603 Kandatsu-Machi, Tsuchiura-shi, Ibaraki Pref., Japan

## ABSTRACT

The authors have studied the automation of exterior wall sealing work in order to secure stable quality and achieve safety of work at high altitudes. The automation system is divided into two functions: operating and supporting. The operating function consists of four subsystems including cleaning, primer coating, insertion of back-up material, and filling with sealant. The supporting functions consists of two subsystems, moving and sensing. This report describes the study results of two of the above subsystems: filling with sealant and sensing. For the filling with sealant subsystem, 2 parts silicone sealant is used. The base compound and curing agent for the 2 parts silicon sealant are mixed at the specified proportion and discharged. This subsystem consists of two types of pneumatic pumps, a measuring cylinder, and a static mixer. The test results shows that both the mixing proportion and discharge were in the allowable range. The sensing subsystem measures the positions and width of joints by using an ultrasonic sensor. Although the sensing accuracy varied depending on the relationship among distance between the sensor and the wall surface, moving speed of the sensor, and the joint width, it was found that the sensing subsystem could be used without problems under presumable actual conditions. Exterior sealing work can be automated only when all the aforementioned subsystems are established. However, the study confirmed that the filling with sealant subsystem and the sensing subsystem were fully effective elements of the technology.

## 1. Introduction

The prefabrication of exterior wall members of buildings has advanced significantly as represented by curtain wall technology, increasing the requirement for more effective waterproofing and airtightness of the sealant used on joints. Sealing work demand is also increasing on the exterior walls of reinforced concrete construction, not only around openings but also on crack control joints, structural joints, etc. Thus, at present, exterior wall sealing work must result in stable quality and safeness of working in elevated locations.

To meet such demands, the authors have studied the automation of sealing work on exterior wall. In this report, a total system concept and test results of the element technology are described.

## 2. Total Concept of Automated System for Exterior Wall Sealing Work

### 2.1 Subject Work and Subject Joint Size

Taking into account (1) quantities of work handled, (2) need for automation, (3) general type of exterior wall, (4) independent automation effect, etc., the subject work of this system was determined as follows:

- Buildings under 15 stories (about 45 m tall)
- Buildings without gondola guide on external wall
- Panel type curtain wall
- New construction work (no-scaffolding method)

Table 1 Joint sizes for this study

(Unit: mm)

| Width / Depth | 10 | 15 | 20 | 25 | 30 |
|---|---|---|---|---|---|
| 10 | o | o | o | | |
| 15 | | | o | o | o |

As renewing work requires other exterior wall work than sealing work, performing sealing work alone using the no-scaffolding method becomes meaningless. Therefore, the subject work of this system was determined to be limited to new construction work. The joint sizes for this study were chosen as shown in Table 1.

### 2.2 Changes in Operation for Automation

Conventionally, sealing work has been performed using the procedure shown in Fig. 1. As most of these operations constitute manual work, not only a review of the tools used, but also changes in the content of operations, changes in sequence, etc., were performed in the designing of the automated system. Major changes are shown in Table 2.

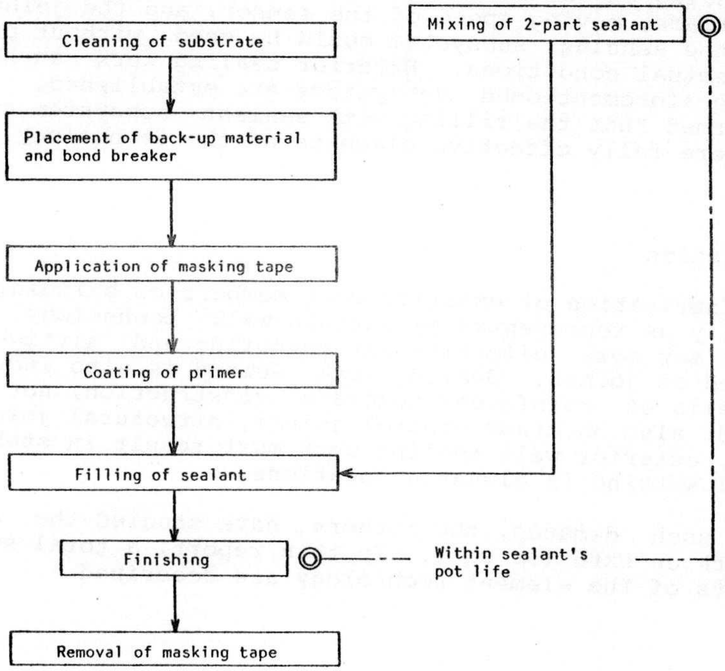


Fig. 1 Conventional operation procedure

Table 2 Changes in operation for automation

| Items | Conventional operation | Automated system | Reasons |
|---|---|---|---|
| Omitting of operation | Application of masking tape.<br>Removal of masking tape. | Omitted. | Operation of automated system permits accurate movement. Sealant's overflow can be managed by adjustment of the filling nozzle. |
| Changes in sequence | Placement of back-up material.<br>Coating of primer. | Coating of primer.<br>Placement of back-up material. | To secure the needed time to dry the primer coating before sealant filling. Disadvantages due to changes in sequence (damage to primer coating surface at the time of placement of back-up material) can be prevented in the automated operation. |
| Method of applying material | Sealant adjusted batch-by-batch. | Sealant is continuously mixed and supplied in parallel with the filling operation. | Labor-savings, securing of material quality. |
| Combining of operations | Filling of sealant.<br>Finishing. | Finishing can be performed simultaneously with filling of sealant. | Adjustment of the filling nozzle permits both operations to be performed simultaneously. |

## 2.3 System Composition

The concept of the automated system based on the basic changes noted above is as follows:

As shown in Fig. 2, this system consists of <u>operation system</u>, which includes four sub-systems, that is, cleaning, coating of primer, placement of back-up material and filling of sealant, and <u>two support systems</u>, namely sensing and movement. The function and methods of these systems are explained below:

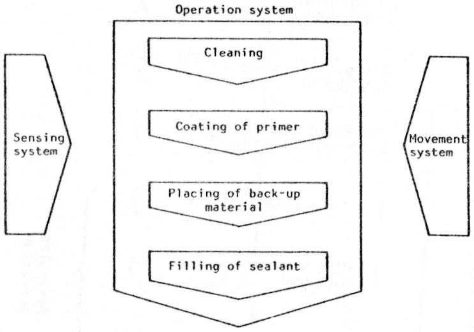


Fig. 2 System Composition

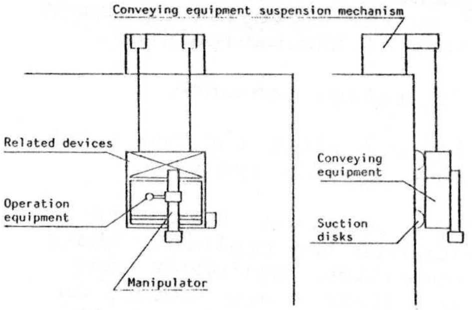


Fig. 3 Conceptual drawing of movement system

(1) Cleaning system --- is the operation of removing foreign matter adhering to the joints (dirt, dust, laitance, oil, etc.) using a rotary brush while spraying solvent.

(2) Coating of primer system --- is the operation of coating the primer on the side face of the joint to improve the bonding between substrate and sealant. A felt brush, continuously drip-soaked with primer, coats the side face of the joint.

(3) Placement of back-up material system --- is the operation of forming the joint bottom for filling of sealant by forcing back-up material made of polyethylene foam in tube form into the joint using a rotary roller. Changes in joint width can be managed by adjusting the diameter of the back-up material using a heated wire.

(4) Filling of sealant system --- is the operation of filling of sealant into the joint while generating a filling pressure in order to allow the bonding of the sealant on the side face of the joint. In this system, the method is adopted in which a 2-part sealant is pumped, mixed and discharged into the joint using a nozzle incorporating the finishing pallet. A change in joint width can be managed by controlling the velocity of nozzle movement.

(5) Sensing system --- is the system for detecting joint position and change in joint width and for the supply of data to the operation system using an ultrasonic sensor.

(6) Movement system --- is the system to move the operation equipment along the joint, and consists of a suspension mechanism for the conveying equipment and the manipulation of the conveying equipment. The conveying equipment is suspended from the rooftop and fixed to the wall face using suction disks. The manipulator in the conveying equipment can move in triaxial directions, i.e. x, y, and z. The operation equipment is loaded on the conveying equipment and moves along the joint in the conveying equipment by means of the manipulator.

2.4 Operation Sequence

Figure 4 shows the operation sequence of this system.

The operation base is provided on the rooftop, where the operation equipment and related devices are loaded on the conveying equipment. The operation equipment is moved with each batch, and the operation within a batch for the vertical joint and horizontal joint covered by the conveying equipment is continuously undertaken with the manipulator.

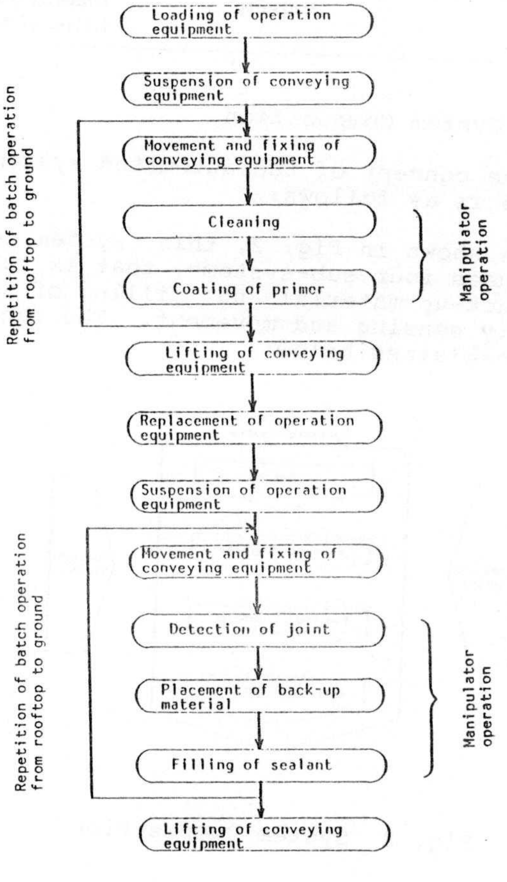


Fig. 4 Operation flow

## 3. Study on Elements Technology

### 3.1 Sealant Filling System

#### 1) Selection of sealant

The sealants used for building construction work at present may be roughly divided into one-component types and two-component types. The classification of base material component may be divided into eight base materials (JIS A 5758). Of these, the two-component type silicone sealant was adopted for use in this report. The reasons for this are described below:

(1) Generally, the two-component type sealant are selected for buildings similar to the one in this study from the viewpoints of cost and performance.

(2) It is assumed that the scope of application of the results of this study may be expanded to buildings taller than the subject building in the future. In such case, the use of two-component type silicone sealant would become more frequent.

(3) As the technology for automated weighing, automated mixing and quantitative discharge of high viscosity materials has not necessarily been established, there is technical significance in using a two-component type sealant.

(4) The dependence of viscosity, etc., on temperature is smallest in the case of a silicone sealant, making it easy to handle in the testing stage. Table 3 shows the items of the sealant used. To accommodate the sealant for use in automation, sealant prepared by uniformly mixing base agent and pigment in advance was used in this study.

Table 3 Items of sealant used

| | |
|---|---|
| Mixing proportions | By weight Base agent : curing agent = 10 : 1<br>By volume Base agent : curing agent = 10.77 : 1 |
| Specific gravity | Base agent 1.30<br>Curing agent 1.40<br>After mixing 1.31 |
| Allowable tolerance of mixing proportions | 10% |
| Viscosity | Base agent about 200,000 cps<br>(Consistency in accordance with JIS K 2220 260-270)<br>Base agent about 15,000 cps |

#### 2) System composition

Figure 5 shows the composition of this system, a summary of which is as follows:

(1) Base agent and curing agent, respectively, are transferred from separate tanks to the two-component weighing device through separate lines.

(2) Base agent and curing agent are weighed in the two-component weighing device to the specified mixing proportions and sent to the static mixer.

(3) The two components are stirred and mixed in the static mixer.

(4) The mixed components are discharged via the nozzle.

(5) Material transfer is accomplished by air pressure generated by base agent pump and curing agent pump.

(6) Variation in the discharge quantity due to change, etc., of the air pressure of the pumps may be adjusted mechanically using the power cylinder installed on the weighing device.

(7) The weighing device has a dead center and at that point, the discharge quantity changes greatly, so the nozzle is closed off for a designated time.

(8) For cleaning the mixer, a tank for solvent and flush pump are provided. And, as the curing agent has high reactivity, $N_2$ is charged in the pump.

The discharge quantities of this system are as shown in Table 4 provided the velocity of the nozzle movement is 1.2 m/min versus the joint size studied.

3) Mixing capability

(1) Weighing performance

The accuracy of weighing ratio was measured by receiving base agent and curing agent discharged from the weighing device in a container at this side of the mixer. Table 5 shows the results of the test. The test results show: 9.73:1-10.81:1 versus the required mixing proportion by weight of 10:1, indicating no problems.

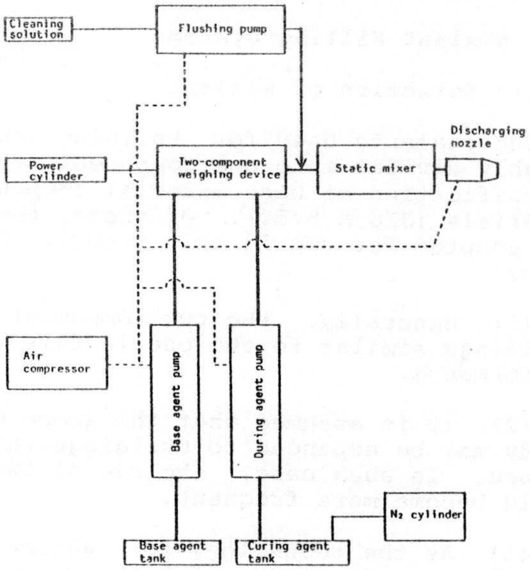


Fig. 5 Basic system chart of sealant fillint system

Table 4 Established discharge quantity

| Joint size (width x depth, mm) | Discharge quantity (cc/min) |
|---|---|
| 10 x 10 | 120 |
| 15 x 10 | 180 |
| 20 x 10 | 240 |
| 20 x 15 | 360 |
| 25 x 15 | 450 |
| 30 x 15 | 540 |

Table 5 Weighing results

| Established discharge quantity (liters/min) | Discharge quantity of base agent (g/min) | Discharge quantity of curing agent (g/min) | Weighing ratio by weight (base agent/ curing agent) | Discharge quantity (liters/min) |
|---|---|---|---|---|
| 0.12 | 169.23 | 17.28 | 9.89 | 0.142 |
| 0.18 | 235.64 | 24.22 | 9.73 | 0.198 |
| 0.24 | 280.92 | 28.26 | 9.94 | 0.236 |
| 0.30 | 381.84 | 38.88 | 9.82 | 0.321 |
| 0.36 | 433.20 | 42.03 | 10.31 | 0.363 |

### (2) Discharging performance

The discharge quantity of sealant mixed in the mixer was measured using two methods, as follows:

a) The weight of the sealant in paste form discharged from the end of the nozzle immediately after mixing was measured by receiving it in a container. Figure 6 shows the results. The correlation between discharge quantity Z (liters/min), base agent pump pressure X ($kgf/cm^2$) and inverter scale Y is shown by the following formula:

$$Z = 20.22X + 4.55Y - 7.56$$

Coefficient of correlation = $\gamma_{YZ} = 0.8606$
$\gamma_{XZ} = 0.9775$

Multiple coefficient of correlation = $\gamma_{zxy} = 0.9874$

The scatter of the discharge quantities was found to be within 6%.

b) The variation in the discharge volume was measured by receiving sealant discharged from the nozzle on a machine-glazed paper that moves at a constant speed (1500 mm/min), cutting the linear sealant by 25 mm in length (equivalent to discharge time of 1 sec) and measuring the weight thereof. Figure 7 shows the results. As noted from the figure, as the discharge quantity increases, the scatter increases showing the effect of the dead center.

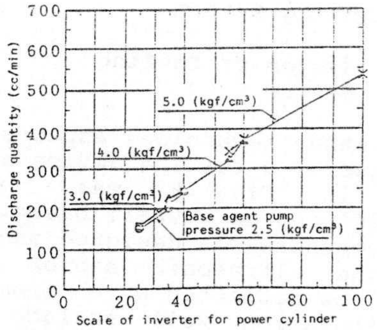


Fig. 6 Measurement results of discharge quantity

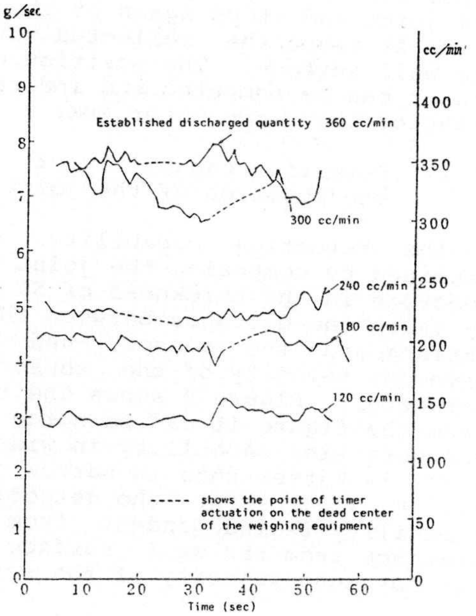


Fig. 7 Variation in discharge quantity

### (3) Physical properties of sealant

The sealant mixed after the conventional method (with rotating drum mixer, automatic inversion type) and the sealant mixed in the present system after fully vulcanized were compared by means of tensile test of sheet material. The test pieces were prepared on the same day and time, after curing for two weeks and formed into No. 3 dumbbell-shaped test pieces in accordance with JIS K 6301 used for the tensile test. Table 6 shows the results. As noted in the table, no problems occurred in the sealant obtained by this method in terms of physical properties.

Table 6 Physical properties of sealant after hardening

| Method of modulus | 150% modulus | Maximum coefficient of extension |
|---|---|---|
| Conventional method (using a mixer of rotating drum automatic inversion type) | 1.8 (0.1)*1 | Larger than 1380%*2 |
| Sealant filling system | 1.8 (0.1)*1 | Larger than 1350%*2 |

*1 Scatter of measurement results n = 9

$$\sqrt{\frac{\Sigma(\bar{x}-xi)^2}{n-1}}$$

*2 No rupture occurred within the scope of the testing machine.

## 3.2 Sensing System

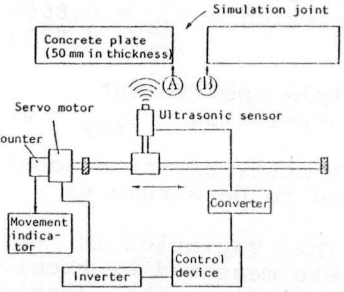
### 1) System of testing device

To study technology aspects of sensors, a testing device as shown in Fig. 8 was manufactured on a trail basis. The mechanism was designed such that the ultrasonic sensor traps the reflected wave from the simulation wall surface when moving in the horizontal or vertical direction and stops at the position where the reflected wave can no longer be detected. It also moves across the joint and stops again at the point where it traps the reflected wave of the wall surface. The position of the sensor can be computed and indicated by means of the servo motor RPM.

### 2) Detection capability of the position of the joint

The detection capability was examined by composing the joint using concrete in the thickness of 50 mm, and by using the distance between the wall surface and the sensor, and the movement velocity of the sensor as a parameter. Figure 9 shows the results. From the figure it can be noted that the detection capability in wider joint is better than in narrow joint and in wider joint the detection capability is independent from the distance from the wall surface and the movement velocity of the sensor.

In the case where the joint width becomes narrower, the sensor mechanism detects the end point (B) simultaneously when removement starts though the stopping signal may be obtained at the starting point of the joint, making it impossible to obtain the data for computing the joint width. However, the sensor was able to detect the position of the joint as long as the joint width was larger than 10 mm.



° Movement velocity may be varied continuously by means of the converter between 75-2300 mm/min.
° The mechanism stops the servo motor at the starting point A and end point B of the joint.
° Indicates movement distance by means of the servo motor RPM.

Fig. 8 Conceptual drawing of sensor testing device

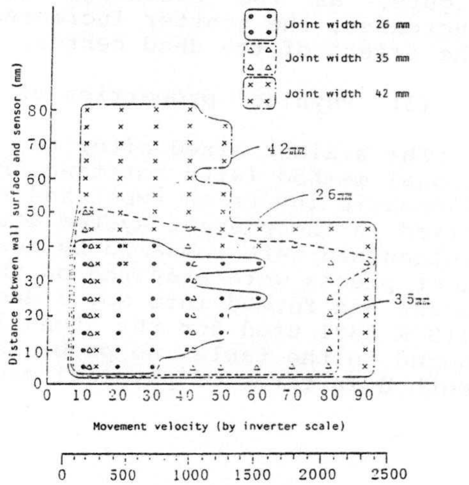


Fig. 9 Detection capability of ultrasonic sensor

### 3) Slippage of position detected

A difference between the detected position and the actual position of the joint was caused owing to the directionality of the sonic sensor and the time difference between receiving the detection signal and motor stoppage. Figure 10 shows the example of measurement results. As noted from the figures, the tendency is that the stoppage position of the sensor slips in the direction of movement as the movement velocity increases.

In contrast, Fig. 11 shows an example of computing the joint width based on the movement distance as indicated. As the figure shows, the computed joint width tends to be smaller than the actual joint width. In the range of the movement velocity of the sensor established by the authors et al (within the scope of the inverter-scale of 40-80), the position and width of the joint can be computed using the following formulas:

. In the case where the distance between the wall surface and the sensor (d) equals 25 mm:

$$A = A' + 7.17 + 0.15x$$

$$B = B' - 11.83 + 0.35x$$

$$W = \frac{B' - A'}{0.315 + 0.0075x}$$

. In the case where the distance between the wall surface and the sensor (d) equals 35 mm:

$$A = A' + 5.83 + 0.15x$$

$$B = B' -17.00 + 0.5x$$

$$W = \frac{B' - A'}{0.200 + 0.013x}$$

Where,

A, B: starting point and end position of the joint.

A', B': starting point and end position of the joint, indicated values

x: scale of the inverter (movement velocity)

W: width of joint

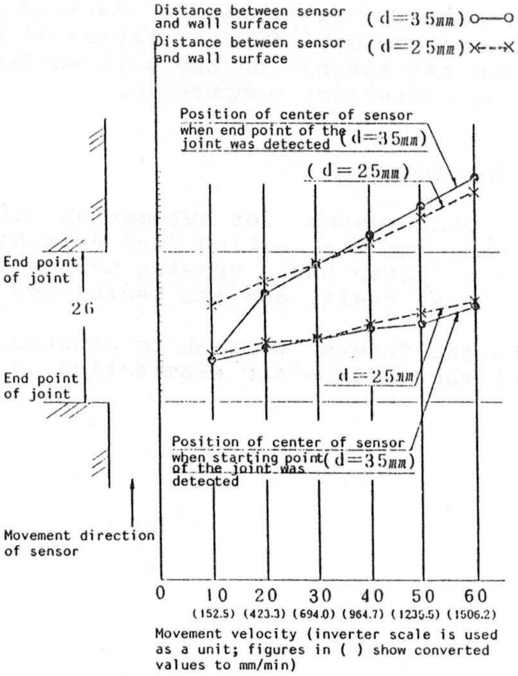


Fig. 10 Sensor position at the time of direction of joint position

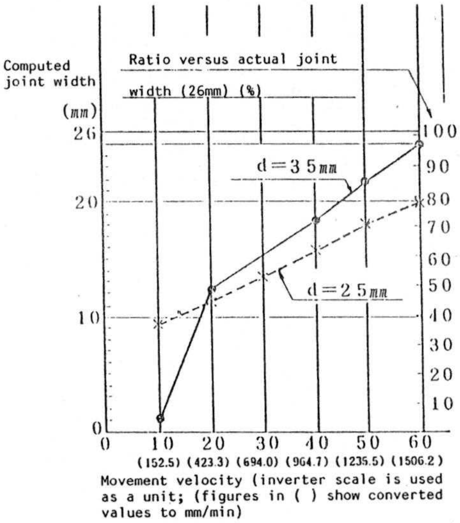


Fig. 11 Joint width computed from distance counter

The sensing mechanism as examined above was found to be sufficiently useful technology for automation of sealing work by keeping the distance between the sensor and the wall surface and movement velocity and by performing corrective computation.

## 4. Conclusion

A total system for automation of exterior wall sealing work was planned, and its testing and examination were performed on a sealant filling system and a sensing mechanism by manufacturing the part thereof on a trial basis, and its usefulness was confirmed.

In the future, we seek to construct a system by performing additional trial manufacture and examination on other systems.