

# EFFICIENT PIPE INSTALLATION SUPPORT METHOD FOR MODULE BUILD

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Commission V, WG V/1

**KEY WORDS:** Space-Borne Scanner System, 3D Sensors, Aerial Survey, Data Integration, Industrial Measurement

## ABSTRACT:

The number of large industrial plants being planned and constructed in Japan has increased tremendously in recent times. By reducing the construction costs involved in the development of these plants, authors can reduce the initial investment required, thereby ensuring a more economical use of monetary resources. However, construction work still requires considerable skill and labor. Hence, it is necessary to develop new systems and processes for construction. In this study, authors have investigated the construction of a large plant by means of a fixed method that employs large-scale machinery. In order to reduce the construction costs, authors have considered the module method of construction. Furthermore, authors have also attempted to simplify the machinery involved in the construction, reduce the time required for installation, equalize the work performed on the site, and improve the quality and safety of construction. In order to attain these objectives, authors have presented a CAD-coordinated method for efficient installation of pipes.

## 1. INTRODUCTION

In this study, authors have investigated the construction of a large plant by means of a fixed method that employs large-scale machinery. In order to reduce construction costs, authors have considered the module method of construction in this study. Furthermore, authors have also attempted to simplify the machinery involved in the construction, reduce the time required for installation, equalize the work performed on the site, and improve the quality and safety of construction.

The module used for installing machinery and plumbing in the plant is first produced in another factory, which is established with the field in another place.

The module is then transported to the plant under construction. The plant is built by connecting several modules using pipes. Therefore, it is very important to conform the positions of the ends of the pipe to the positions in the design data.

The conventional method for installation of pipes involves first temporarily installing the pipe in the location specified by the design data. The positions of the pipes after each temporary installation are then manually verified by a measurement method. The measurements are performed using a tape measure and bob.

If the measured position of the installed pipe varies from that in the design data, the pipe is first removed, reinstalled, and then its position is measured again. This process is continued till all the pipes are appropriately installed (in accordance with the positions in the CAD drawing). It is apparent that the above procedure is time consuming and involves a considerable amount of skill and labor. Moreover, it is necessary to periodically check the positions of the pipes till the entire pipe installation work is completed. This method requires high precision as inaccurate installation of the pipes considerably increases both the time and labor required.

In order to reduce costs and develop highly precise modules, it is necessary to develop a system that can measure the position of a pipe and then move it in the direction of the position specified by the CAD drawing. The system should also be able to display the movement of the pipe in real time and reduce the amount of skill required, while maintaining high precision.

## 2. CONVENTIONAL MEASUREMENT METHOD FOR MODULE BUILD

The first step while constructing a plant using the module method is to assemble the pipe module. Following this, the other modules are connected to each other. Figure 1 shows the pipe module.

The module is assembled by first constructing a frame, which is equivalent to the soil skeleton of the module, according to the 3D coordinates specified by the design of the plant under construction. Next, devices such as pipes are installed in the positions specified by the design data.

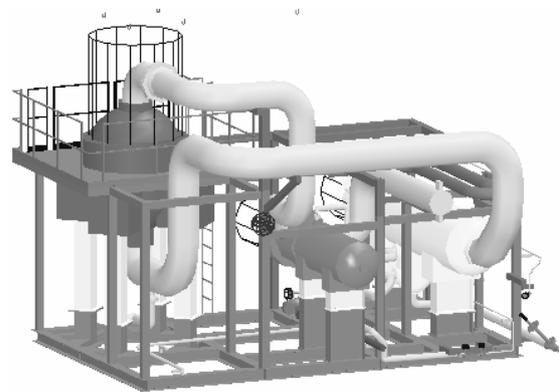


Figure 1. Pipe Module (3D model)

Authors investigated the actual conditions during module assembly to develop a system that supported module assembly. In the conventional method of installation of pipes, the pipes are first temporarily installed and then their positions are validated manually.

If the position of a pipe does not match its position in the design data, modifications (removal of pipe, reinstallation, and revalidation) are performed until the position of the pipe conforms to the design data. Thus, considerable time, labor, and skill are required as the validation procedure is continuously repeated till all the pipes are installed.

Furthermore, the conventional method requires high precision because if the installation is inaccurate, considerable time and labor are required for modification.

Hence, it is necessary to develop a method that is both time and labor efficient and that allows us to easily measure the position of a pipe and then move it to the position specified in the CAD drawing.

### 3. SYSTEM COMPOSITION

#### 3.1 Work Flow of The Developed System

In this study, authors have developed an efficient system that measures the central axis position of a pipe (measured position) and then moves the pipe in the direction of the accurate position (the target position in the design data), if required.

While developing a system, it is necessary to consider both the measurement procedure as well as the design of the target position.

Authors have developed a simple system, whose functioning is described below.

Work Flow:

- a. First, the module assembly is designed using 3D CAD.
- b. The desired positions for the installation of the pipes are indicated using specification symbols that denote the position of the central axes of the pipes in the 3D CAD design.
- c. Based on the positions specified in the design, information for the target positions is then automatically generated.
- d. 3D measuring equipment is installed for onsite base point measurement.
- e. Measurement information is acquired using the 3D measuring equipment (Measurement of the position of the central axis of a pipe).
- f. The measured and target positions are compared and the results are displayed.
- g. Based on the displayed results, the pipe is then moved to the target position.

As mentioned above, first, the positions of the central axes of the pipes are indicated by means of specification symbols in the module assembly drawing developed using 3D CAD.

Target position information such as the 3D coordinates is generated by considering the positions of the symbols in the CAD drawing. The generated information is then delivered to the 3D measuring equipment.

The 3D measuring equipment measures several base points on the site to perform CAD data and the correspondence account

of the field coordinate system, and location of the measuring equipment is kept under control.

Following this, an arbitrary point is selected from a checklist of several target positions and the position of the central axis is measured at this point.

Based on the measurement information, the positions of the pipes in the module are then adjusted until the target positions specified in the design have been achieved.

#### 3.2 Developed Subsystems

The position of central axes of pipes are specified in the CAD drawing to allow efficient generation of target position information as well as to provide a reference for the validation of the pipe positions.

Authors investigated a system to automatically install the pipes according to the central axis positions specified in the target position information. The following subsystems (a-c) were developed to implement this system.

Developed Subsystems:

- a. An automatic system that installs a pipe according to the location of the central axis specified in the CAD drawing
- b. A jig, manufactured on a trial basis, which measures the position of the central axis of the pipe
- c. A display system that shows the difference between the target position of the pipe and the temporary position of the pipe in real time  
(Display of movement and direction of movement of a pipe)

#### 3.3 Development Environment of the System

Authors used a laser tracker (3D measuring equipment) to enable automatic tracking of the position of the central axis of the pipe. The other machinery utilized by the system is listed in Table 1.

	Function	Term	Additional Information
Hard-ware	3D measuring equipment	Laser Tracker	+ Range accuracy: Less than 0.050 mm + Measurement distance:0-35m + Automatic tracking function of target
	Equipment to measure Pipe location	Jig	-
	Controller	PC	Windows PC
Soft-ware	CAD system (design data editing)	Commercial CAD system	Original development function is incorporated
	Development language A	C++	Used for development of control software
	Development language B	LISP	Used for creating original development function in CAD system

Table 1. System Development Environment

Our system was used to assemble a pipe module at the module assembly plant. When technique was used in other locations, system construction using general-purpose supply was expected (Because, there was machinery rotation at the time of ability increase).

Authors used a CAD system to design the module. The CAD system used in this study was a commercial CAD system that could be easily customized and which was capable of handling general CAD data as well.

#### 4. TECHNOLOGIES USED IN THE DEVELOPED SYSTEM

##### 4.1 Extraction of Data from CAD Drawing

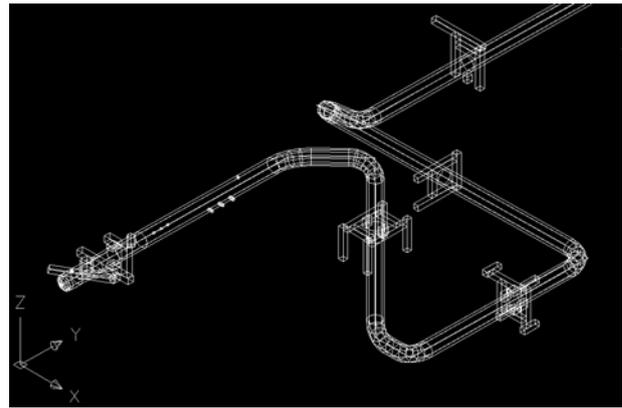
In this study, authors developed a system that used the position data in the CAD drawing to automatically generate target position information. The application screen of this system is shown in figure 2.

Figure 2 (a) is the CAD data that pulled out the part of the module assembly drawing, and figure 2 (b) is the example which a specification symbol was mentioned in figure 2 (a). The target position information was generated by considering the position of the predetermined specification symbols in the 3D CAD drawing. A circle was used to indicate the central axis of pipes, as observed in figure 2 (c), and a facility was developed that allowed us to list the specification symbols used in the design.

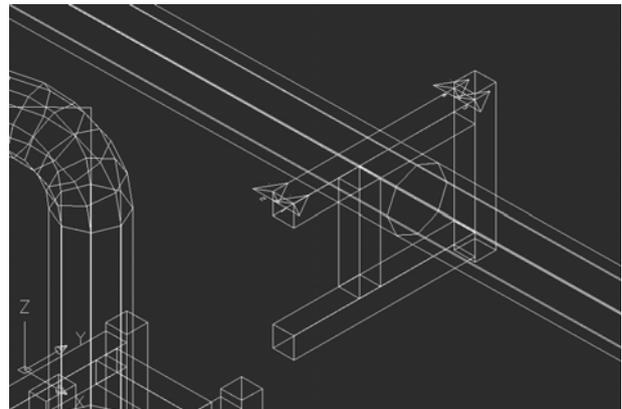
In case the central axis of a pipe was not indicated by a circle, an intersection of the line which meant pipe center in the perimeter which was appointed on three-dimensional CAD data was searched for automatically. A facility was developed that allowed us to list the specification symbols used in the drawing sheet.

The statement following of the specification symbol, target position information can be displayed as a checklist to show it in figure 2 (d) by considering authorized symbol rank relationship on the three-dimensional CAD data. Furthermore, the target position information can be adjusted to show it in figure 2 (e) about the target position information after the preparation by appointing arbitrary point.

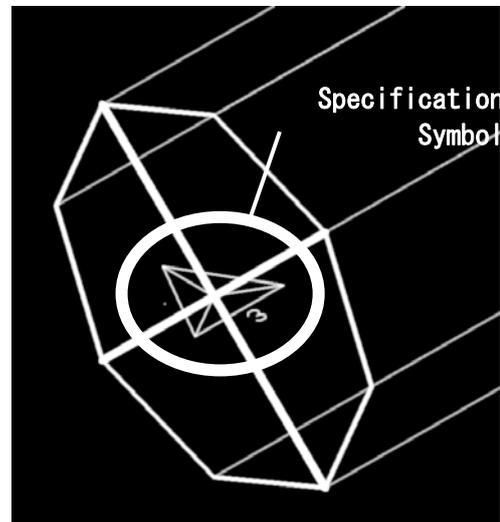
After the preparation and modification of the target position information were completed, the listed data were saved in a file and delivered to the laser tracker.



(a) 3D CAD data(Module)



(b) Specification Symbol Statement CAD Data



(c) Specification Symbol in the circular graphics

Figure 2. Application Screen of The CAD Linkage Target Position Production System



(d) List of Target Position Information Preparation Result

(e) Target Position Information Modification

Figure 2. Application Screen of System used for Generation of Target Information

#### 4.2 Efficient Pipe Installation Method using Laser Tracker

To accurately determine the position of a pipe, it is necessary to determine the position of the central axis of the pipe. Using the laser tracker, the position of the central axis of the pipe can be tracked automatically.

In this study, authors developed an experimental jig that allowed us to measure the position of the central axis of a pipe and thereby install the pipe accurately.

It should be noted that pipes of several different sizes were used in the assembly of the module. Therefore, the jig first examined the structure to ensure that it could support pipes of different sizes.

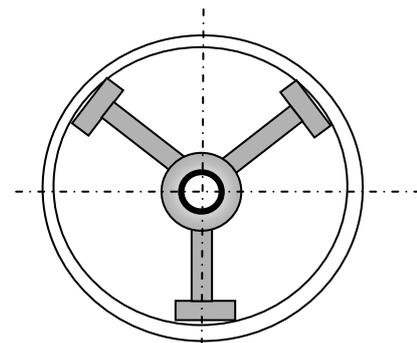
### 5. SYSTEM DETAIL AND PERFORMANCE

#### 5.1 Measurement Support Tool

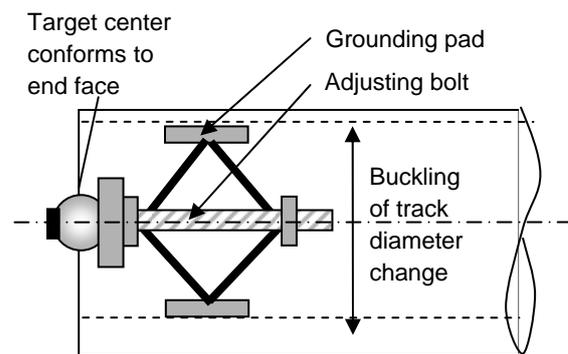
To compare a target position with acquisition of the measurement position and measurement position in real time, the central axis position of the pipe have to be always measured. Figure 3 is a functional diagram of the central axis position measurement jig.

As for the pipe size used for module assembly, there is several sizes. Therefore, a structure to post grounding pad on the equivalency from adjusting bolt installed along a pipe central axis was adopted.

Figure 4 is a central axis position measurement jig produced experimentally based on a functional diagram shown in figure 3. The measurement target can possess preparation voltage head. And the guide is grown by three direction for a pipe end face from the neighbourhood of target.

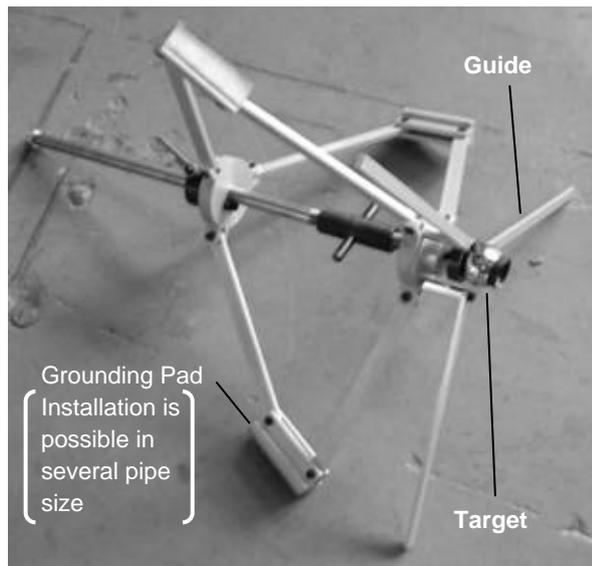


(a) Front Image



(b) Side Image

Figure 3. Central Axis Position Measurement Jig Functional Diagram



(a) Main Body



(b) Usage Situation

Figure 4. Jig used for Measurement of Central Axis Position

### 5.2 Display System

To synchronize the target position and measured position, authors developed a system that displays the difference between the target position and the measured position in real time in a simple manner that can be easily understood by authorized personnel.

In this study, authors used the automatic tracking function of the laser tracker to determine the position of the pipe.

Furthermore, authors also developed a function that compares the target position information with the measured position information in real time.

The results of the comparison are shown as numerical information. The relationship between the measured position

and target position is also displayed visually. Thus, the authorized personnel can view both visual information and numerical information at the same time. The display is shown in figure 5.

The display content changes in real time with the change in the measured position of the pipe. For instance, if a worker moves a pipe in the wrong direction, the displayed results change to reflect the fact that the pipe has shifted away from the target position.

In order to effectively install a pipe, the display screen showing the results of the measurement should be confirmed at any time. The measurement screen can be generally confirmed with measuring equipment control machine.

Authors incorporated a device in the control system of the measuring equipment to transfer the results of the measurement to an external monitor by radio.

Therefore, the display screen can show the results of measurements performed even in remote locations. Thus, the results of a measurement process can be observed not only at the construction site but also at some other optional place. Using the results, a worker can compare the measured positions and target positions and the migration length of the pipe in real time.

Therefore, a work to confirm measurement result in measuring equipment of the remote place from a pipe and a work moving the pipe by an incomplete designation (voice only) from measuring equipment employer disappear. Thus, there is an improvement in the quality of work.

### 5.3 Accuracy

Authors used a jig to measure the position of the central axis of a pipe. However, some errors were observed in the measurements. Authors measured three different dimensions of the pipe with the aid of eight equidistant points that were distributed on the circle. Authors obtained the center (central axis position) of the circle by applying the results of the measurement to the equation of the circle. Furthermore, mean value of measured result was adopted for most probable value by the same method five times. Five times of measurement with the central axis position measurement jig was performed afterwards.

The precision of the measurements was investigated by comparing the most probable value with the results of the measurement. Table 3 shows the precision of the measured values.

Jig Kind	Central Axis Position Measurement Jig
Standard deviation	0.32 mm
Inaccuracy	0.92 mm

Table 2. Precision for measurement validation result

It was observed that by installing the pipe using the measurements obtained by the jig, the error in the installation was less than 1 mm. This fact is confirmed by the results shown in Table 3.

#### 5.4 Effectiveness of The System

While assembling the module, it is necessary to align both ends of the central axis of the pipe with their target positions.

Therefore, the position of the central axis needs to be measured at both ends and rationalization effect for the pipe position alignment time was confirmed by confirming time before moving to a target position.

Authors calculated the total time required to assemble the module by measuring the time required to adjust the position of the pipe and the time required to move the pipe into position.

From the results, it can be observed that our system requires only half the time of the previous labor-intensive method to complete the assembly of the module. Furthermore, by using our system, the relationship between the measured position and the target position can be confirmed at any instant using both numerical and visual information. Moreover, our system can also obtain and verify measurements in remote locations. By these functions, effect was provided for the rationalization of the pipe fixed work.

#### CONCLUSION

The system that authors have developed in this study has several remarkable features such as its ability to generate data from CAD drawings and its ability to accurately install pipes.

The CAD data generated by the system can also be utilized for other targets. Authors plan to improve our pipe-installation system through further investigations.

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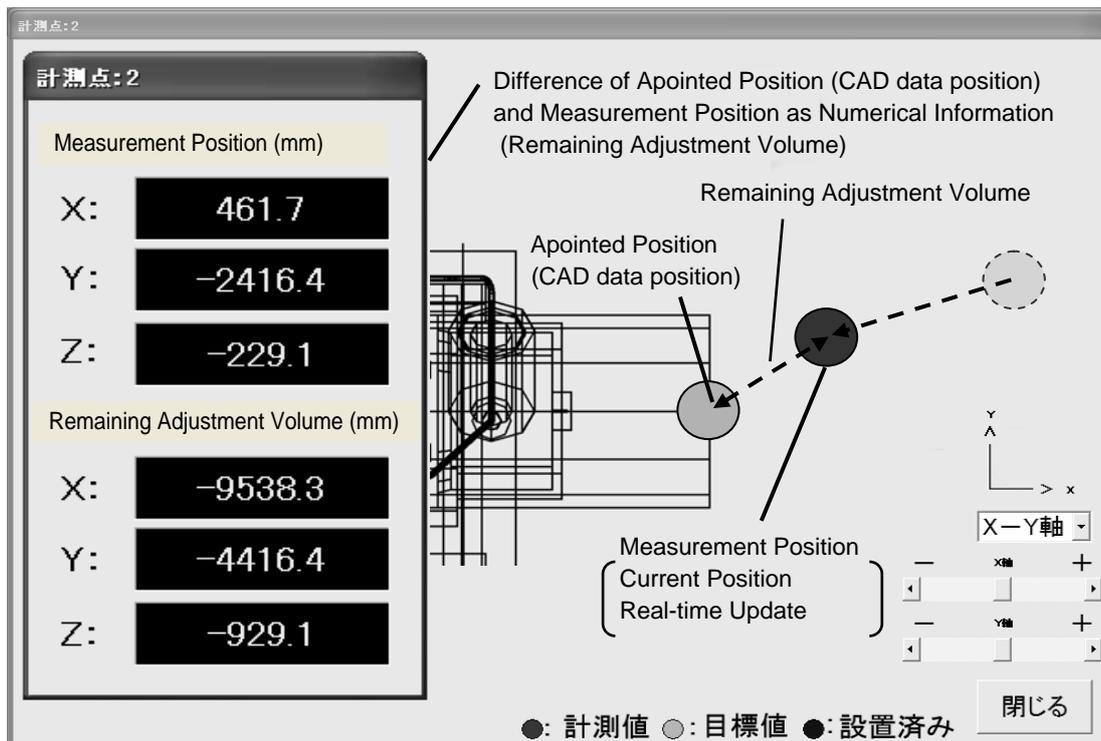


Figure 5. Measurement Result Display Screen