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ASSEMBLY TOOL DESIGN

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(Received May 7, 1996)

The reactor core of the Internatioal Thermonuclear Experimental Reactor (ITER) is assembled with a number of large and asymmetric components within a tight tolerance in order to assure the structural integrity for various loads and to provide the tritium confinement. In addition, the assembly procedure should be compatible with remote operation since the core structures will be activated by 14-MeV neutrons once it starts operation and thus personal access will be prohibited. Accordingly, the assembly procedure and tool design are quite essential and should be designed from the beginning to facilitate remote operation.

According to the ITER Design Task Agreement, the Japan Atomic Energy Research Institute (JAERI) has performed design study to develop the assembly procedures and associated tool design for the ITER tokamak assembly. This report describes outlines of the assembly tools and the remaining issues obtained in this design study.

Keywords : Fusion Experimental Reactor, Remore Handling, Assembly, Tool

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This work is conducted as a ITER design study and this report corresponds to 1994 ITER design Task Agreement on "Assembly Tool Design" (S22TD04 Task ID:D29).

+ Department of ITER Project

JAERI-Tech 96-023

トカマク組立機器の設計検討

日本原子力研究所那珂研究所核融合工学部
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多田　栄介・関　　昌弘

（1996年5月7日受理）

国際熱核融合実験炉（ＩＴＥＲ）の中心部分は，複数の大型で非対称形状を有する機器が組み合わされて構成されている。これらの機器の組み立てでは，核・熱及び電磁力など種々の荷重条件下でそれらの構造健全性を担保するため，またトリチウム格納の障壁を保証するために，厳しい組立精度が要求される。また，炉の中心部分はＤＴ燃焼により放射化されるため，これらの機器の再組立・保守は全て遠隔操作で行うことが要求される。このため，組立手順及び組立ツールの設計は極めて重要であり，設計当初から遠隔操作によって重量物の高精度取扱を可能とする様考慮することが必要である。

この様な観点から，原研ではＩＴＥＲ設計タスクの一環として，ＩＴＥＲトカマクの組立方法及び組立ツールの設計検討を進めてきた。本報告では，この設計検討で明らかとなったＩＴＥＲトカマク機器の組み立てに用いる組立ツールの設計概念及び今後の技術課題について取り纏める。

本研究はＩＴＥＲ工学設計活動の一環として実施したもので，本報告は1994年ＩＴＥＲ設計タスク協定（S22TD04 タスクID：D29）に基づくものである。
那珂研究所：〒311－01　茨城県那珂郡那珂町向山801-1
＋　ＩＴＥＲ開発室

Contents

目　　次

1. Introduction

The engineering design activities of International Thermonuclear Experimental Reactor (ITER) [1] has being conducted by the united efforts of EU, Japan, USA and RF aiming at the demonstration of scientific and technological feasibility of fusion power. In the realization of ITER, the development of the machine assembly is essential, since the components require severe alignment even they are large and heavy. Furthermore, since the reactor core of ITER will be highly activated by 14-MeV neutrons once it starts operation, personnel access will be prohibited so that assembly and replacement of the components inside the cryostat will have to be totally conducted by remote handling technology. Many of assembly procedures will have to be applied to remote replacement at a later time.

Thus, tools to assemble ITER tokamak should be designed so as to be;

1) handling large and heavy components up to 25 m and 3,000 tons.
2) compatible to alignment with high accuracy in the order of a few-mm,
3) fully compatible with remote operation.

In this regard, this paper summarizes the design outline of the handling tools, fixtures and adjusting equipment effective for both the assembly and replacement such as lifting and adjusting fixtures for vacuum vessel and superconducting magnets, mechanisms for attaching jigs, tools for TF-coil keys, tools for back plate pre-assembly, the central fixture, and central measuring system.

2. Design Assumption

In this design study, it is assumed that personal access is possible in a pre-assembly area and full remote operation is required for assembly operation in a tokamak pit. In order to minimize the number of tools, fixtures and adjustment equipment for these pre-assembly and final assembly, they should be designed from the beginning to be compatible with remote operation as much as possible or to be used for remote operation by replacing critical parts of the tools with the remotized elements in advance.

The tool design in this study has been performed according to the assembly procedure as shown in Figs. 1 and 2. In addition, the following assumptions are given as the boundary considerations.

(1) Available lifting device
Overhead crane or gantry crane with a maximum capacity of 4,000 ton
(2) Number of sectors
24
(3) Pre-assembly unit
1) Toroidal Field Coil (TFC) and Vacuum Vessel (VV)
TFC*2 +VV/parallel*2 +VV/wedge*1 +Back plate
2) Center Solenoid Coil (CSC) and Backing Cylinder (BC)
CS + all BC segments
3) Poloidal Field Coil (PFC)
Installed one by one

3. Tool Design

3.1 TFC/VV assembly tool

The tool for the TFC/VV assembly consists of lifting jigs and clamping jigs, as schematically shown in Fig. 3a. The lifting jig is directly attached and fixed to the TF coil case from the top, and the jigs can be lifted together with the pre-assembly unit of TFC, VV and blanket back plate by using the building crane or the heavy lifting transporter. An estimation on the major parameters of the TFC/VV lifting tool is listed below.

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Size	:	5,000W x 13,000L x 23,000H
Weight	:	1,000 ton
Capacity load	:	1,000 ton
Measurable angle	:	+-90 deg.
Measuring accuracy	:	+-0.1 deg.
Adjustable accuracy	:	+-0.2 deg.

In order to avoid the lateral deflection during the lifting operation, a balancing mechanism is inevitably required to adjust the lifting position on the gravity center line of the pre-assembly unit. This functional requirement will be achieved with a balance weight installed at the upper region of VV.

The clamping jigs are installed on the both sides of TFC so as to fix the VV sector and the blanket backplate to the TF coil case, as shown in Fig. 3a. In addition, adjustable turnbuckles are installed inside the back plate so as to prevent an excessive deformation due to the dead weight and to avoid vibration during the lifting operation. The clamping jigs can be installed in the VV port opening space, resulting in consistency with thermal shield layout.

Figures 3b to 3e show the schematic view of the clamping jigs which can be installed in the opening space of horizontal port and pumping duct. The clamping jigs are composed of hydraulic cylinders, supporting rods, links and clamps. According to the dead weight distribution and the geometrical configuration of the pre-assembly unit, the capacity of the hydraulic cylinders in each clamping jig has been chosen as listed below. For fixing the pre-assembly unit during the lifting operation, the minimum number of the clamping jig required for upper port region, horizontal port region and pumping duct region is 1, 4 and 3, respectively.

For grabbing and swinging

· Load capacity	:	20 ton
· Stroke	:	55 mm
· Angle capacity	:	90 deg.

For position adjustment

·Load capacity	:	50 ton for horizontal port and duct
	:	100 ton for upper port
·Stroke	:	50 mm

3.2 CSC/BC assembly tool

Two types of lifting concepts have been investigated for installation of CSC and BC. One is to lift CSC/BC at the bottom region using a lifting rod inserted through the bore of BC, as shown in Fig. 4. Additional rigs are to be attached near the upper part of BC so as to avoid the lateral displacement and vibration during the lifting of a 20-m long heavy component. A pin type joint between the lifting tool and the crane is required for adjusting misalignment between them and providing flexibility. The advantages of this concept are to offer relatively simple and stable gripping of CSC/BC at the bottom and to prevent tension loads acting on CS winding pack during lifting. In addition, reliable self-locking of the gripping rigs during lifting can be attained due to the dead weight of CSC/BC assembly.

Another concept is to lift the upper region of CSC/BC using a number of lifting rods, as shown in Fig. 5. The lifting rods can be attached to the holes of BC segments and a pin type connection between the tool and the crane is also employed as well as the previous concept. The advantage of this concept is that the bore of BC segments can be used for a guide structure space, so that accurate positioning of CSC/BC can be attained since CSC/BC can be installed and removed along the guide structure. Although the horizontal and vertical posture adjustment of CSC/BC can be possible by using turnbuckles of the lifting rigs, the lateral deflection and vibration during lifting will be a fundamental problem.

The major parameters of the CSC/BC lifting tools for both concepts are tentatively estimated as listed below.

Weight of tools	:	~700 ton
Load capacity	:	2,500 ton (dead weight of CSC/BC)
Required accuracy	:	<0.028 deg. for the vertical movement
Turn buckle	:	105 ton for lifting the upper region

3.3 PFC assembly tool

The lifting tools for initial assembly of PF magnets (PFC-2 ~ PFC-7) have been designed according to the dead weight requirements listed below and the spatial constraints. Every tool is basically composed of an inner ring, an outer ring, a number of connecting beams between the rings, and gripping rigs with position adjusting mechanisms. The structural configuration of the lifting tools is shown in Figs. 6 ~ 12 corresponding to each PF magnet, together with the major parameters of the tools, such as weight, dimensions, lifting method, positioning devices and sensors required for the installation operation. The number of the connecting beams is chosen in terms of uniformity of load distribution and reduction of the lifting tool weight.

PFC No.	Lifting Weight [ton]	Remarks
2	550	See Fig.6
3	680	See Fig.7
4	1,400	See Figs.8, 9
5	2,200	See Fig.10
6	680	See Fig.11
7	800	See Fig.12

3.4 Attachment for lifting

In general, several attachment schemes can be applicable to the connecting interfaces between crane and tools, and between tools and components to be lifted. In this design study, efforts have been focused to develop self-locking type attachment since it has attractive features to achieve simple and tight griping, to be cost benefit and compatible with remote operation.

Figure 13 represents possible self-locking type attachment schemes, which are categorized into a hook type, a fluke-lock type and a mechanical lock type. All of them are in principle based on self-locking due to the dead weight of components during lifting.

3.5 Tools for shear key installation

Figures 14 and 15 show the design concept of shear key installation device for TF magnets. The key installation device, which is composed of a turn table, nose key racks, and nose key fixing system, can be installed in a space between TF magnet nose and a reference pole for measurement. The key racks set on the turn table contain a number of nose keys and can be rotated for installation of the keys into keyways between TF magnets. The key fixing system shown in Fig. 15 is composed of a key insertion/removal tool and a screwing tool for fitting the key wedges to the keyways.

The key installation device is designed to be compatible with remote operation and the parallel operation of installing and tightening keys is possible to save the installation period. Using this key installation device, the nose keys can be inserted into the keyways with assembly clearance and the clearance is fitted by adjusting the key wedges after the installation. For this, no pre-compression onto the key wedges is possible and the effects of misalignment and gaps between the keys and the keyways on the structural integrity should be assesses.

3.6 Tools for back plate pre-assembly

Figure16 shows a design concept of the tools to install back plates into vacuum vessel for a unit pre-assembly. In this concept, the back plate is installed along a rail set in the bore of vacuum vessel for pre-assembly purpose: this provides simple movement of the back plate and a wide working space. The supporting jigs are attached to the back plate so as to avoid an excessive deformation due to the dead weight and mounted onto the rail for rotation.

3.7 Central fixture and central measuring system

Figure17a shows a design concept of a central fixture to measure and align the TF position to the reference point. This fixture is also used for a guide structure to install the TFC/VV sub-assembly, the measuring system and the key installation device. Typical parameters of the central fixture is as follows.

Size	:	3,000φ x 25,000H
Weight	:	400 ton
Concentricity	:	0.5mm
Installing accuracy	:	2/1,000 mm

Figure17b shows a design concept of a measuring system attached onto the central fixture. The vertical alignment of the TFC nose can be measured from relative distance between the nose surface and a reference line provided by a bob set on the central fixture. The radial and tangential inclination of TFC are also measured from relative distance between the bob and the TF nose surface.

The distance sensor set on the central fixture can measure these two dimensions at the same time by moving vertically and scanning horizontally along the central fixture. The whole system can be turned around the central fixture for effective installation operation. A laser type potentiometer is considered for this distance measurement and the major parameters of this distance measurement are listed below.

Measuring accuracy	:	2/1,000 mm
Running speed	:	500 mm/min.
Scan speed	:	0.2 rps
Turning speed	:	0.04 rpm
Turning accuracy	:	+-0.1 deg
Sensor	:	Laser potentiometer
Vertical line on TF	:	>3 mm width
Size	:	4,800L x 3,600W x 15,500H
Weight	:	100 ton

4. Conclusion and remaining issues

Although the design improvement of the magnet structure and the supports has been decided after this design study was initiated, the design efforts have been mainly based on the previous reference design due to lack of time to investigate the new reference design. In addition, according to this design transition, the major design conditions such as assembly procedure, structural configuration, support layout and

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interface requirements are not defined for developing the tool design for assembly of the ITER tokamak main components.

Accordingly, this design study has been performed to outline the concepts of tools and fixtures which will be commonly used for heavy component installation. Therefore, the design concept proposed in this report should be reviewed according to the new reference machine layout, structural supports and assembly procedures. In particular, following issues are essential to be considered for the further design development of tools

(1) Assembly and manufacturing tolerance
(2) Assembly clearance
(3) Compatibility with remote operation
(4) Working space
(5) Working environment
(6) Deformation due to dead weight
(7) Structural integrity of tools and components

Acknowledgment

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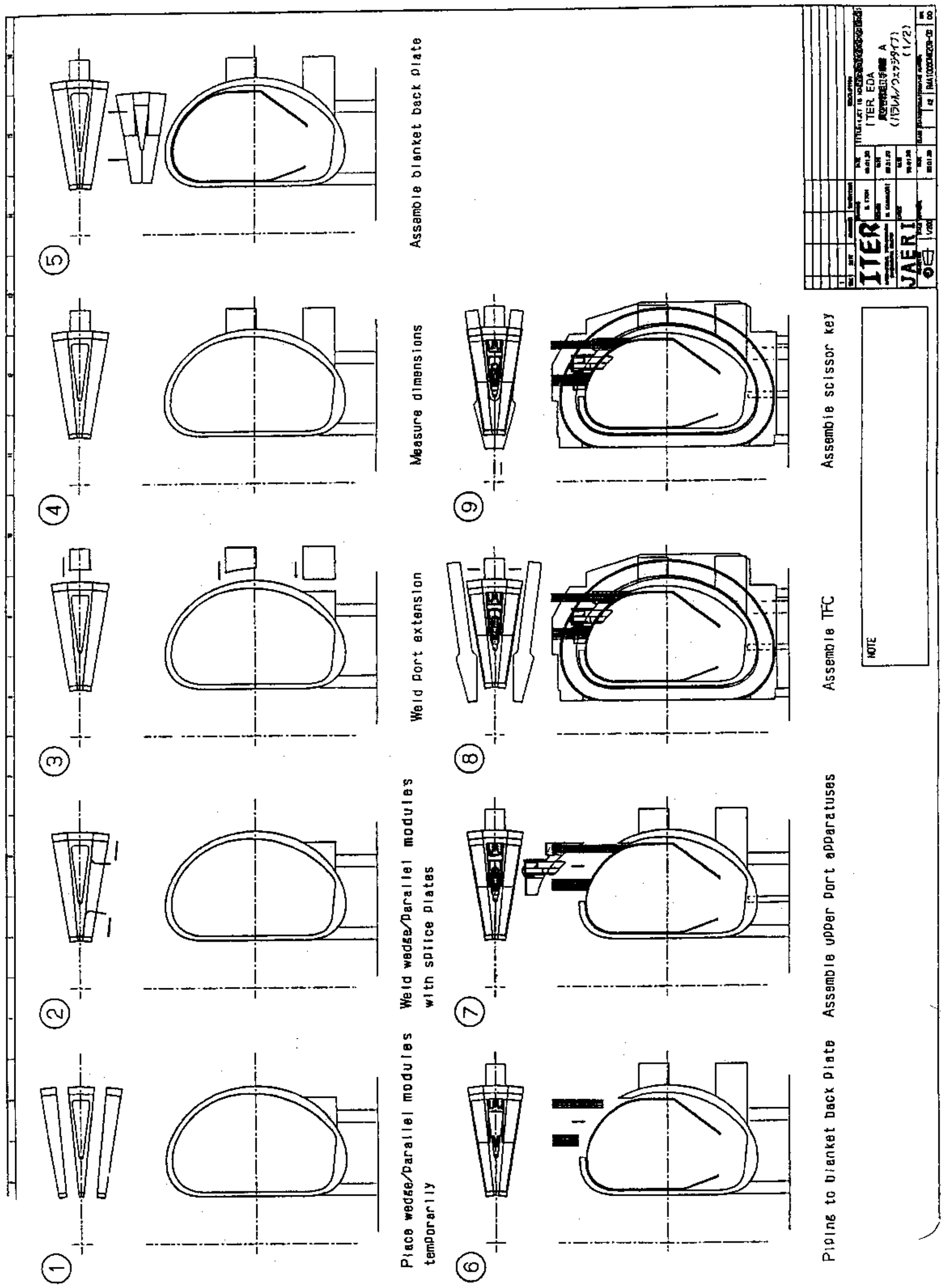

Fig. 1 Assembling Procedure (1/2)

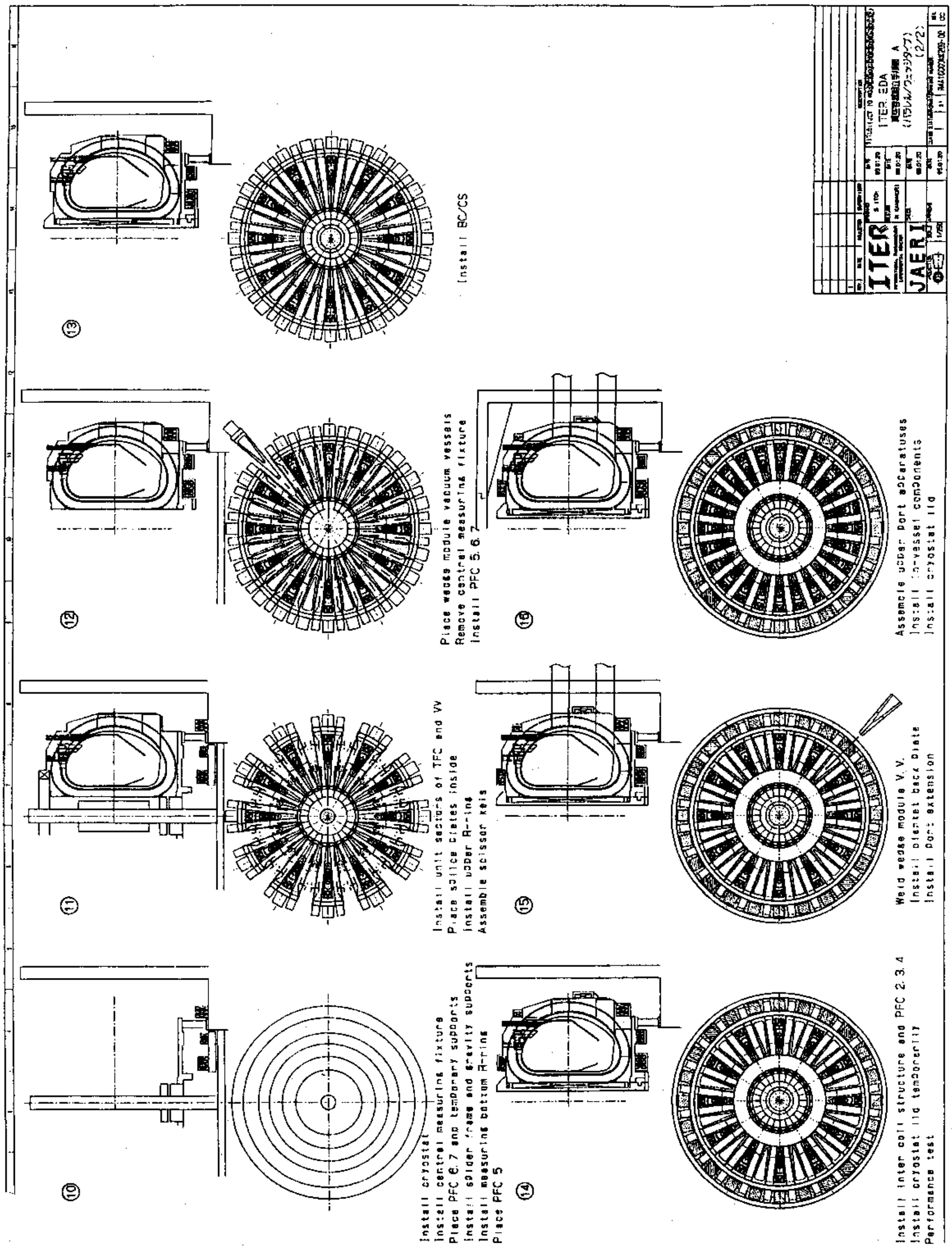

Fig. 2 Assembling Procedure (2/2)

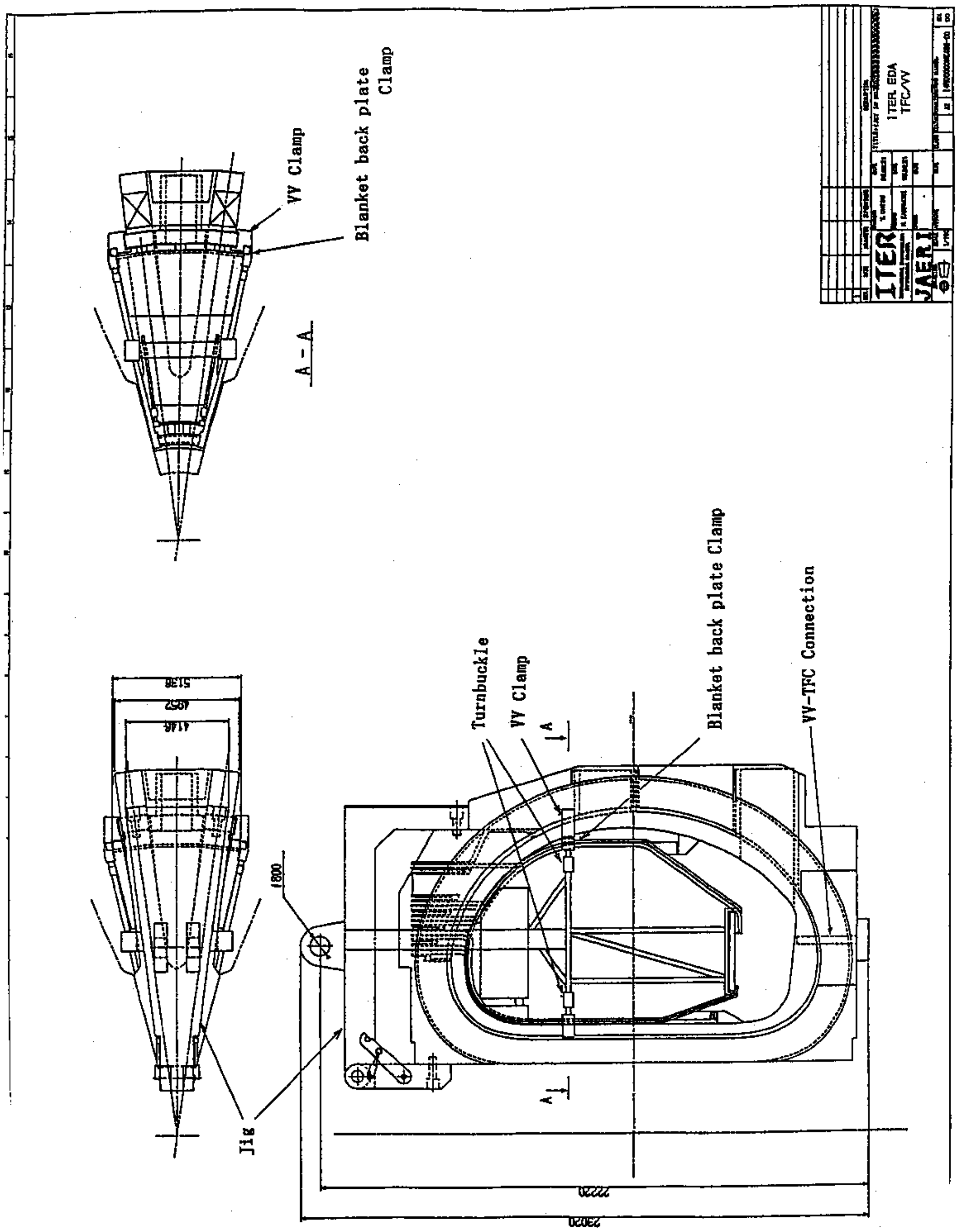

Fig. 3a TFC/VV Lifting Tool

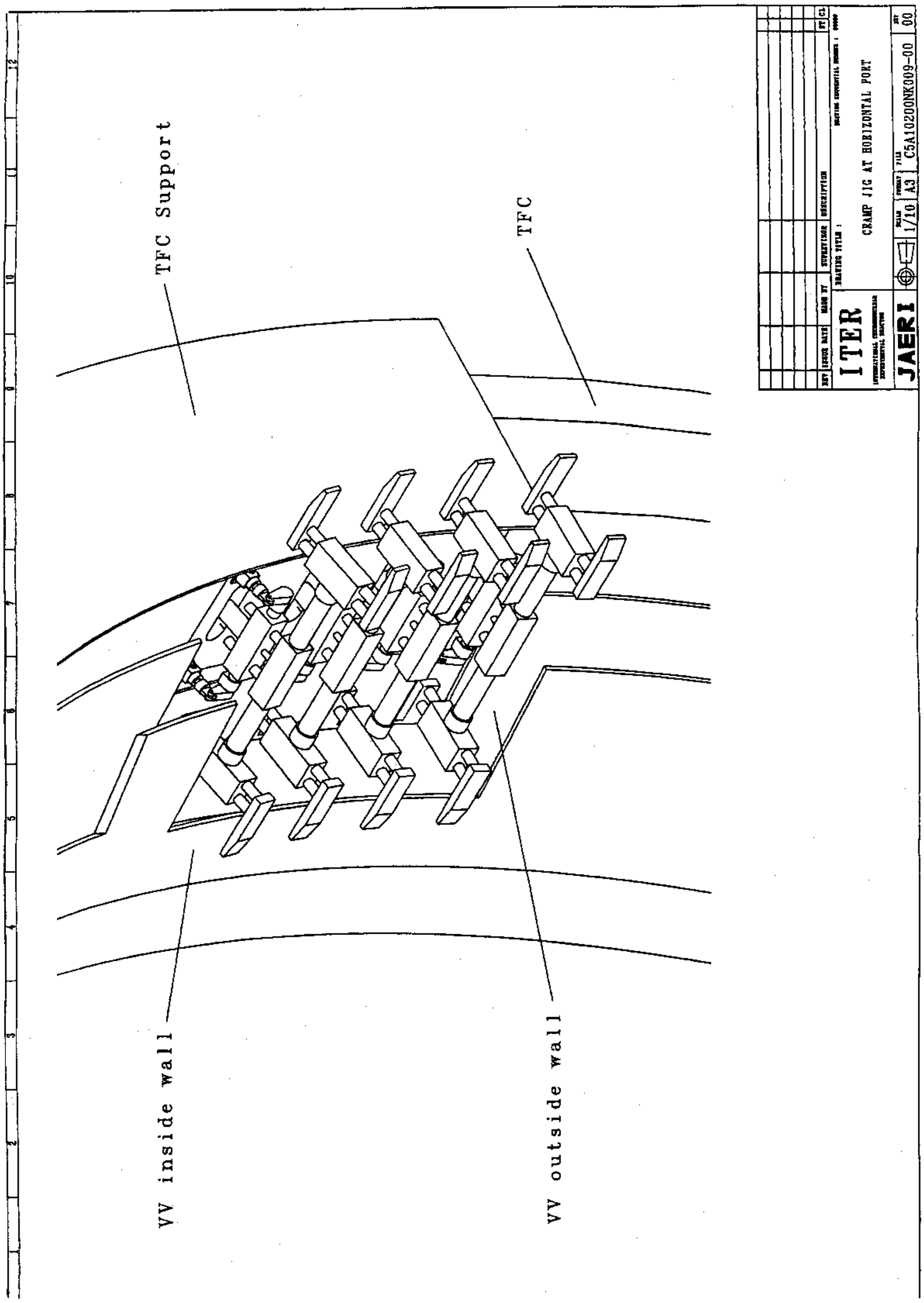

Fig. 3b Clamp jig at horizontal port

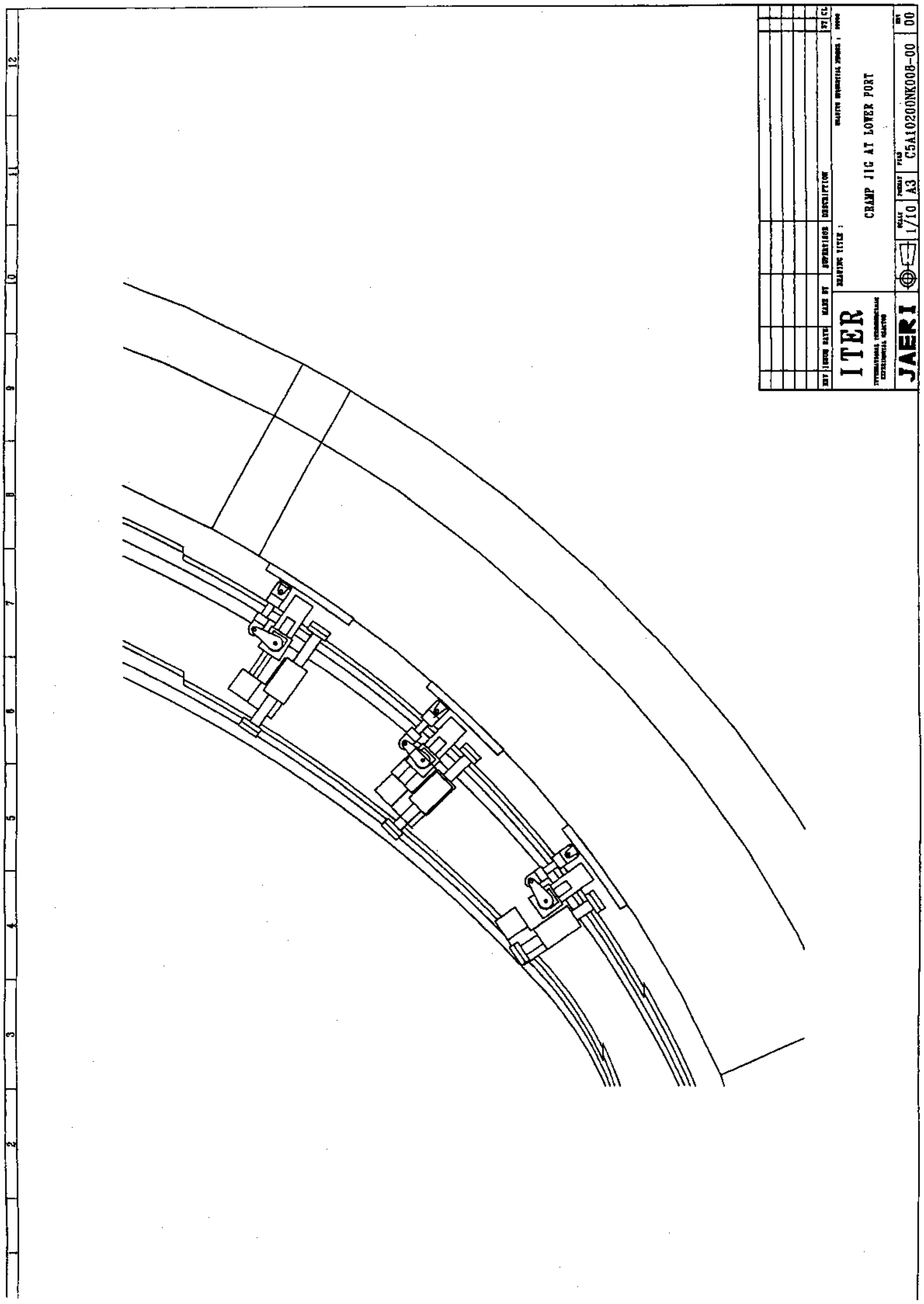

Fig. 3c Clamp jig at lower port

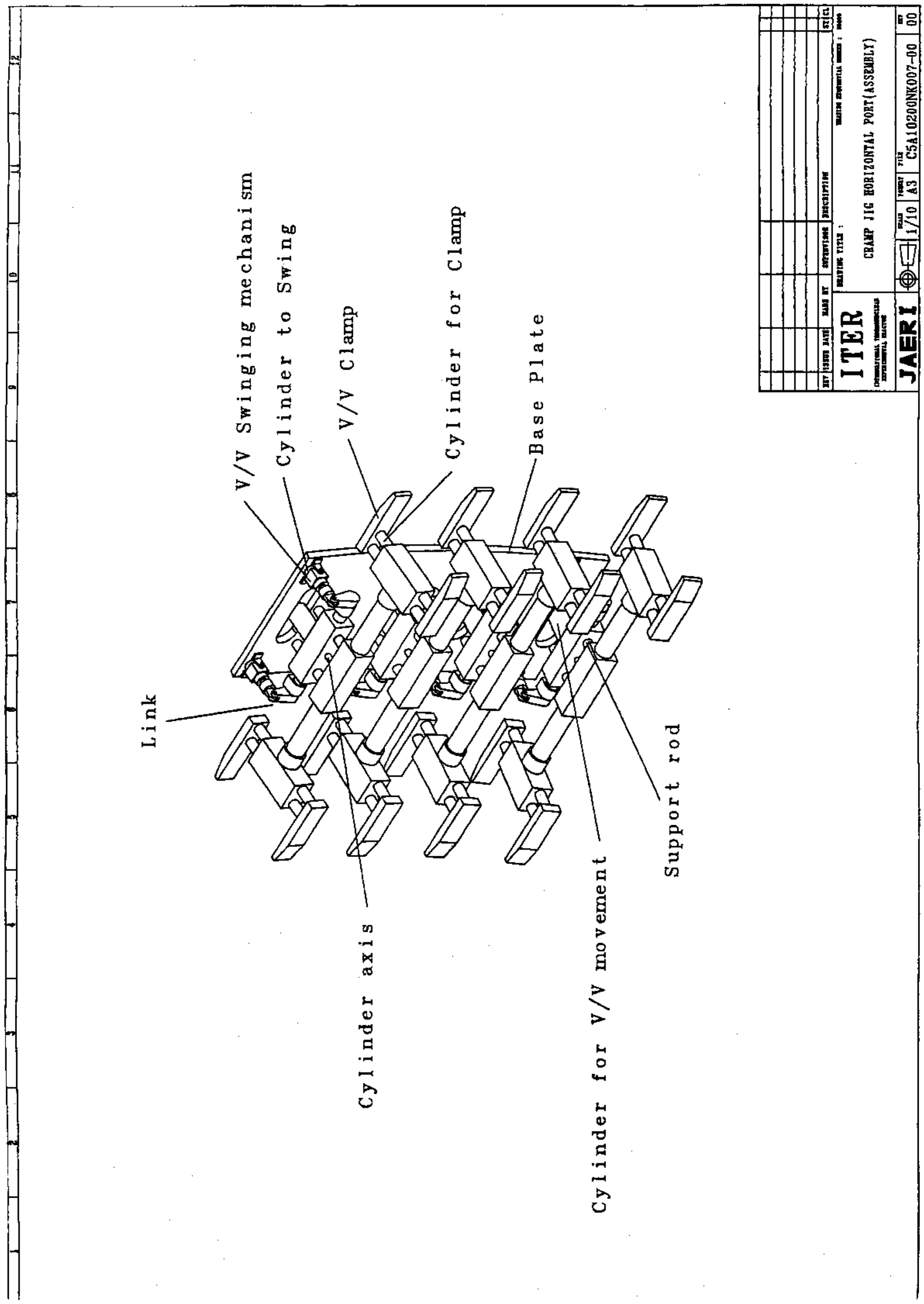

Fig. 3d Clamp jig

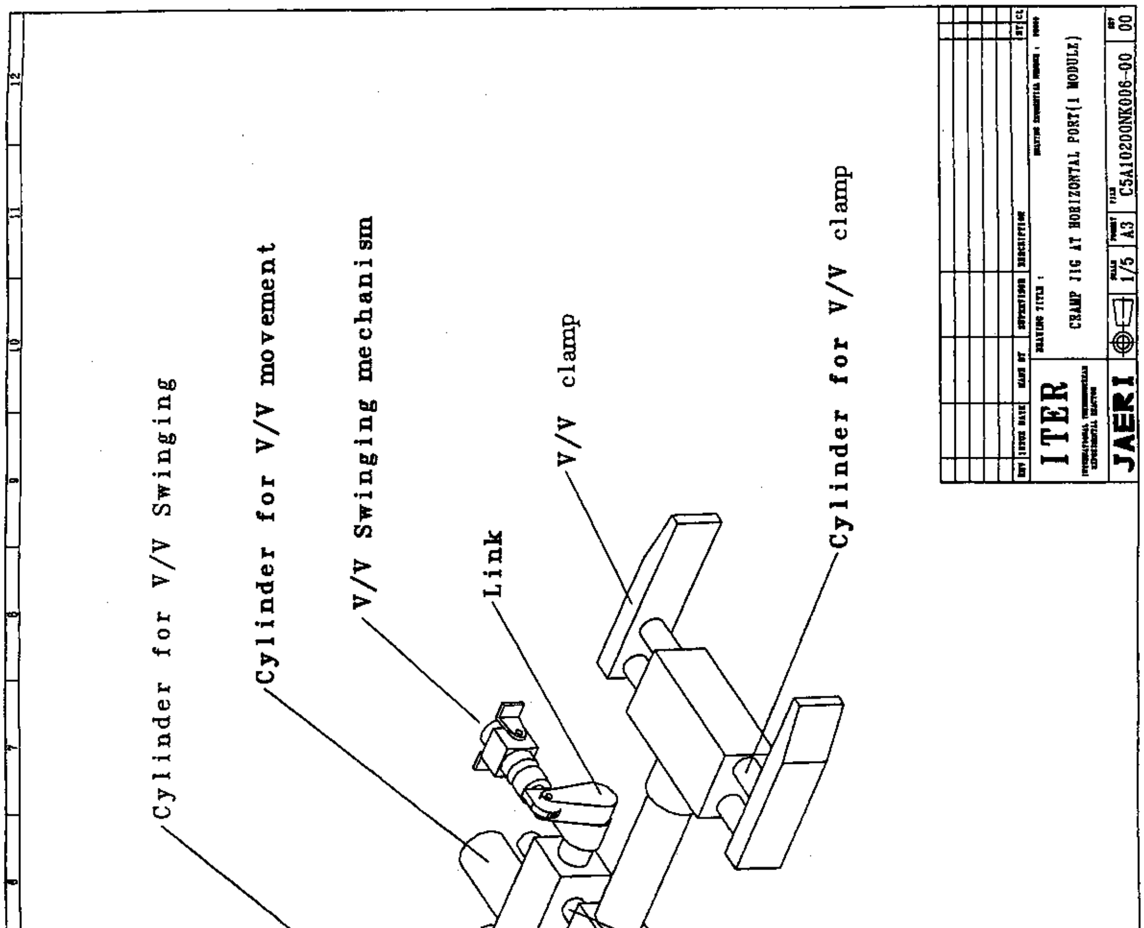

Fig. 3e Clamp jig unit

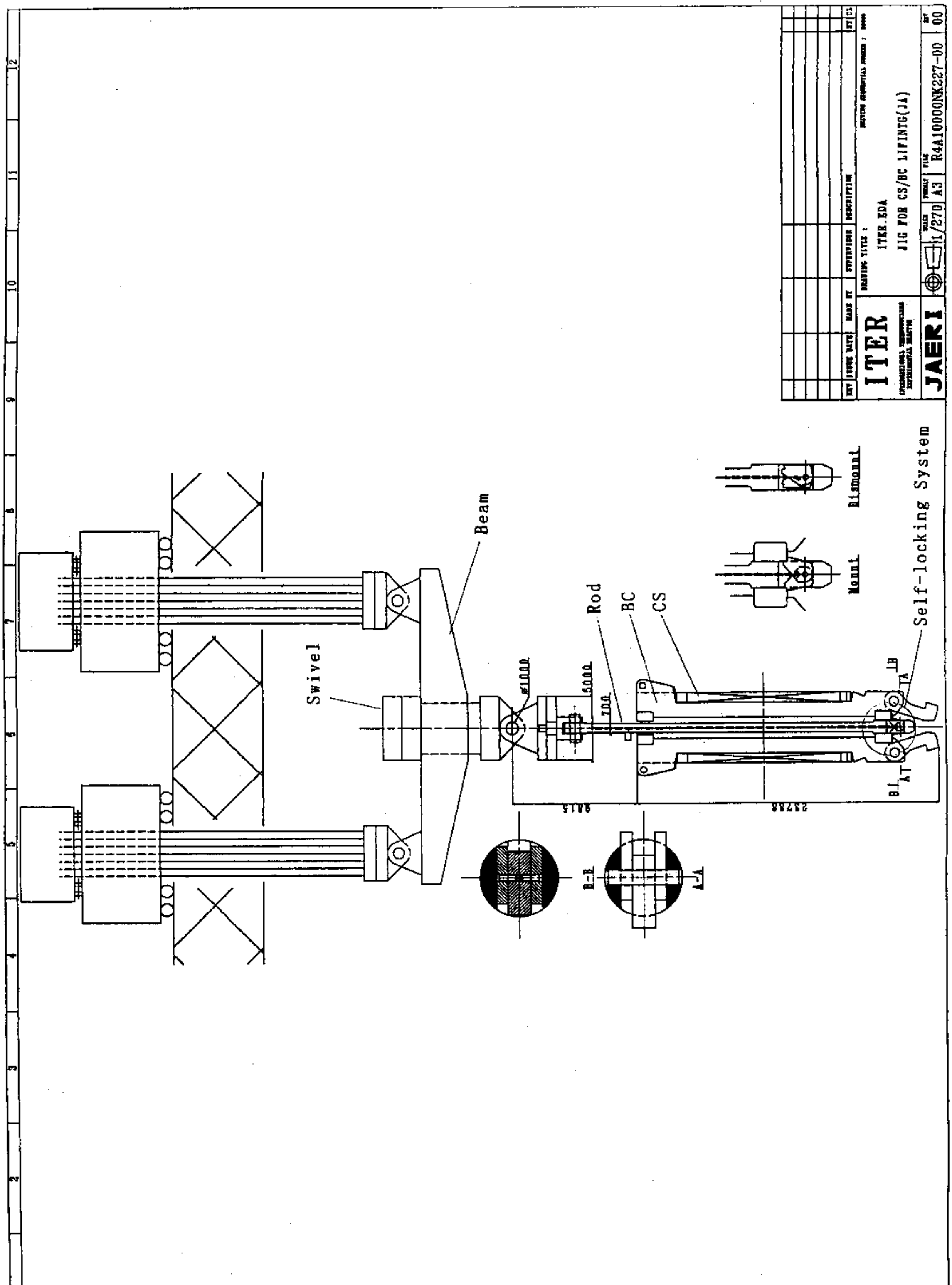

Fig. 4 BC/CS Lifting Tool (Recommendation)

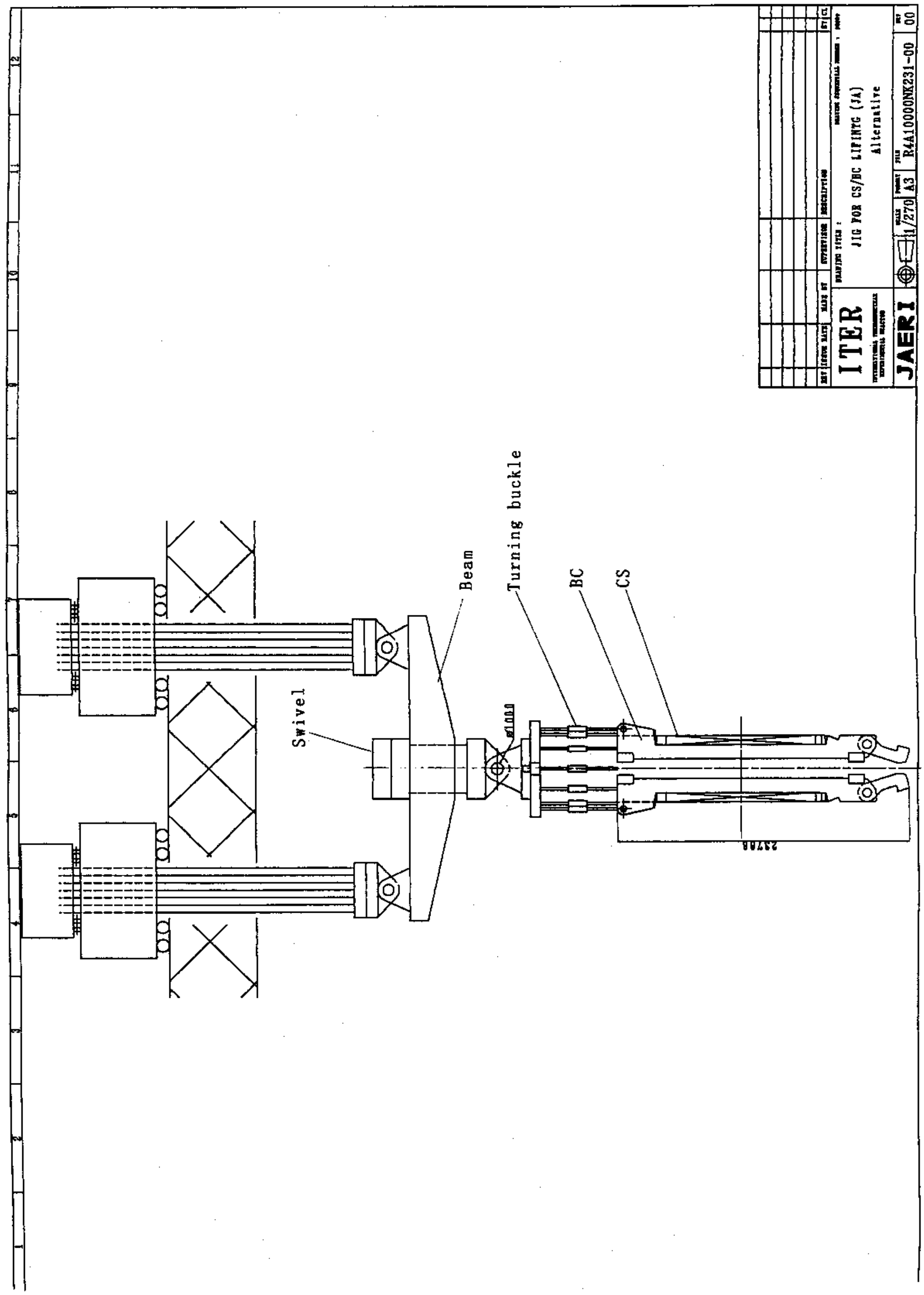

Fig.5 BC/CS Lifting Tool (Alternative)

PF Coil 2

Weight	:	311ton
Width x Height	:	φ12.66m x 1.20m
Lifting Point	:	12 point
Lifting Method	:	Hole Catch
Positioning Device	:	Mechanical Type
Detecting Device	:	Position Detecting Device
		Inclinometer Device
		Acceleration Detecting Device

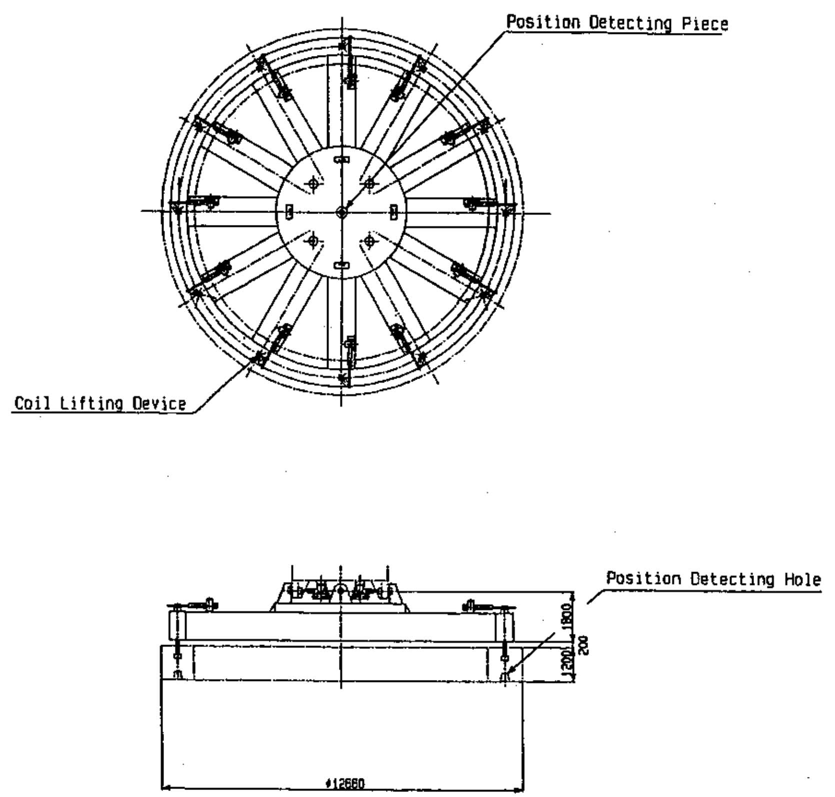

Fig. 6 PFC Lifting Tool (PFC 2)

PF Coil 3

Weight	: 364ton
Width x Height	: φ26.05m x 1.17m
Lifting Point	: 18 Point
Lifting Method	: Hole Catch
Positioning Device	: Mechanical Type
Detecting Device	: Position Detecting Device Inclinometer Device Acceleration Detecting Device

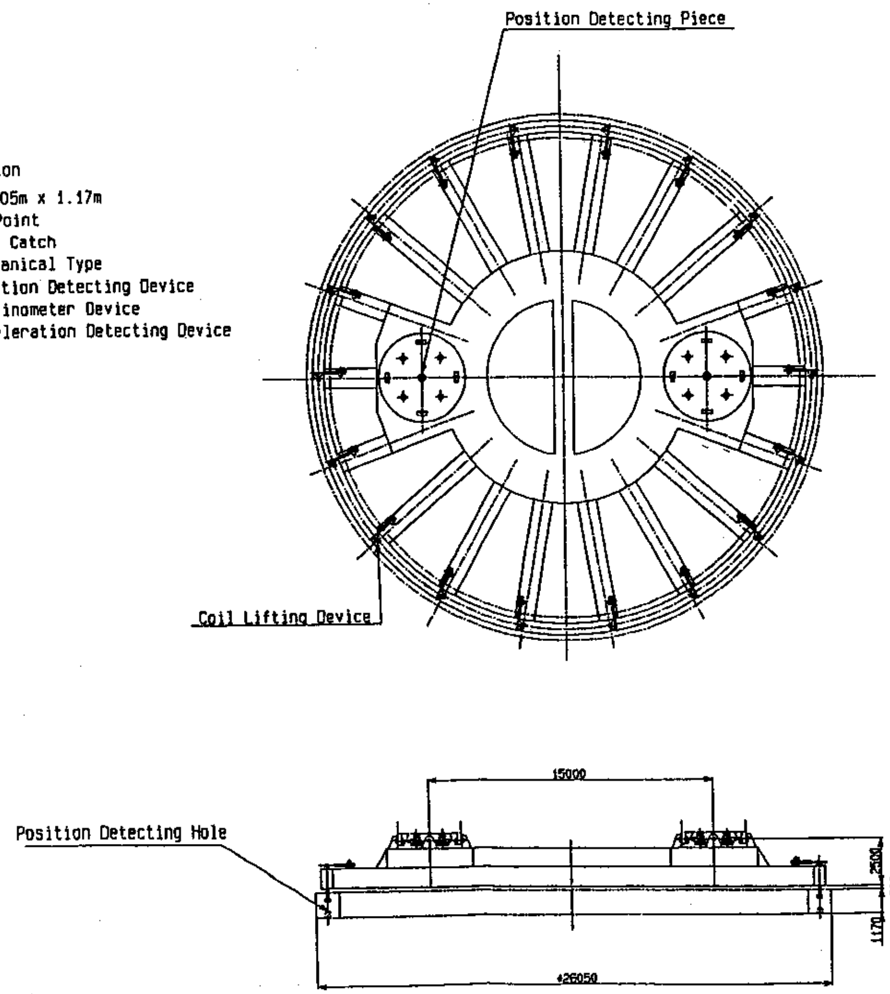

Fig. 7 PFC Lifting Tool (PFC 3)

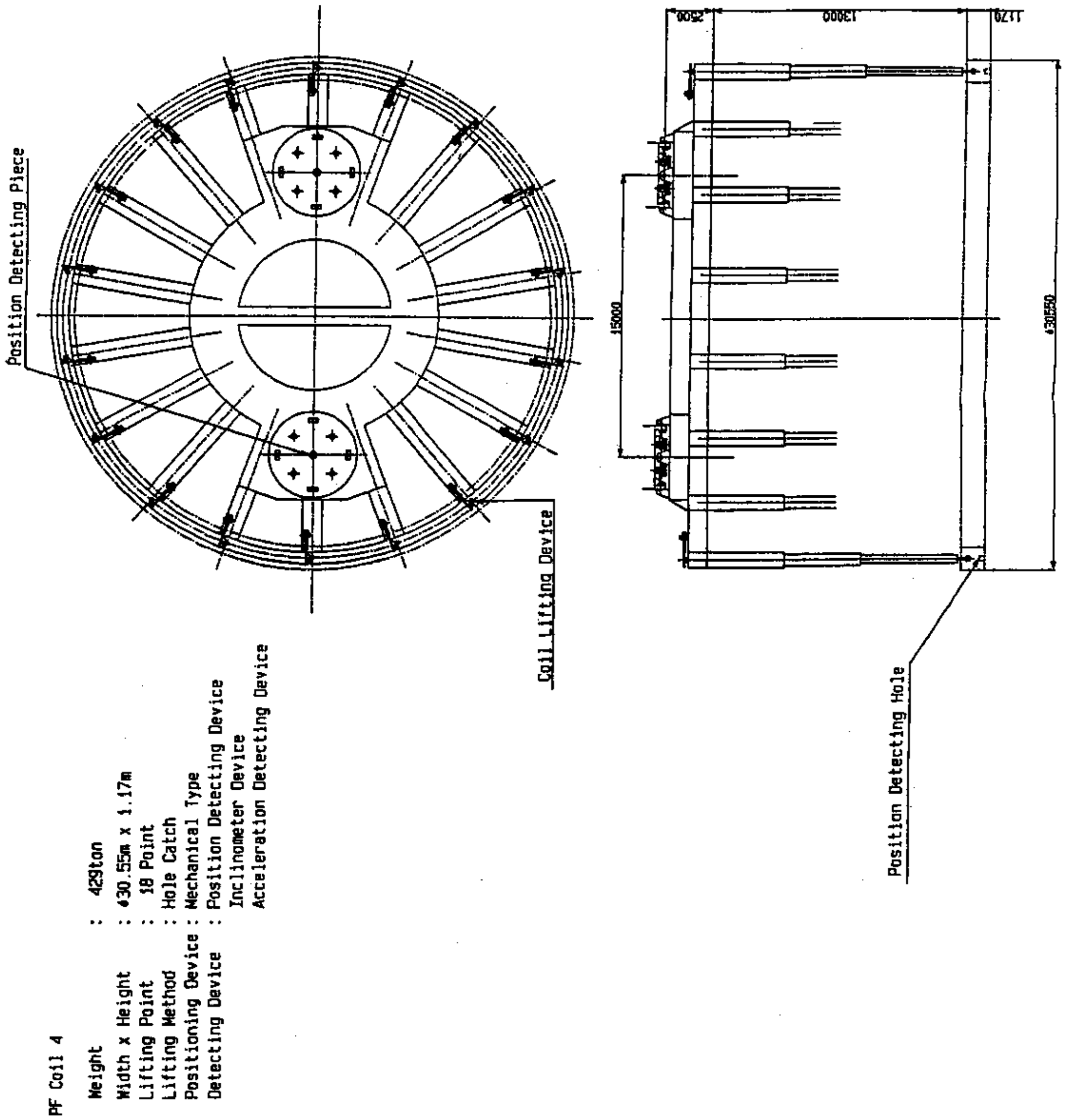

Fig. 8 PFC Lifting Tool (PFC 4)

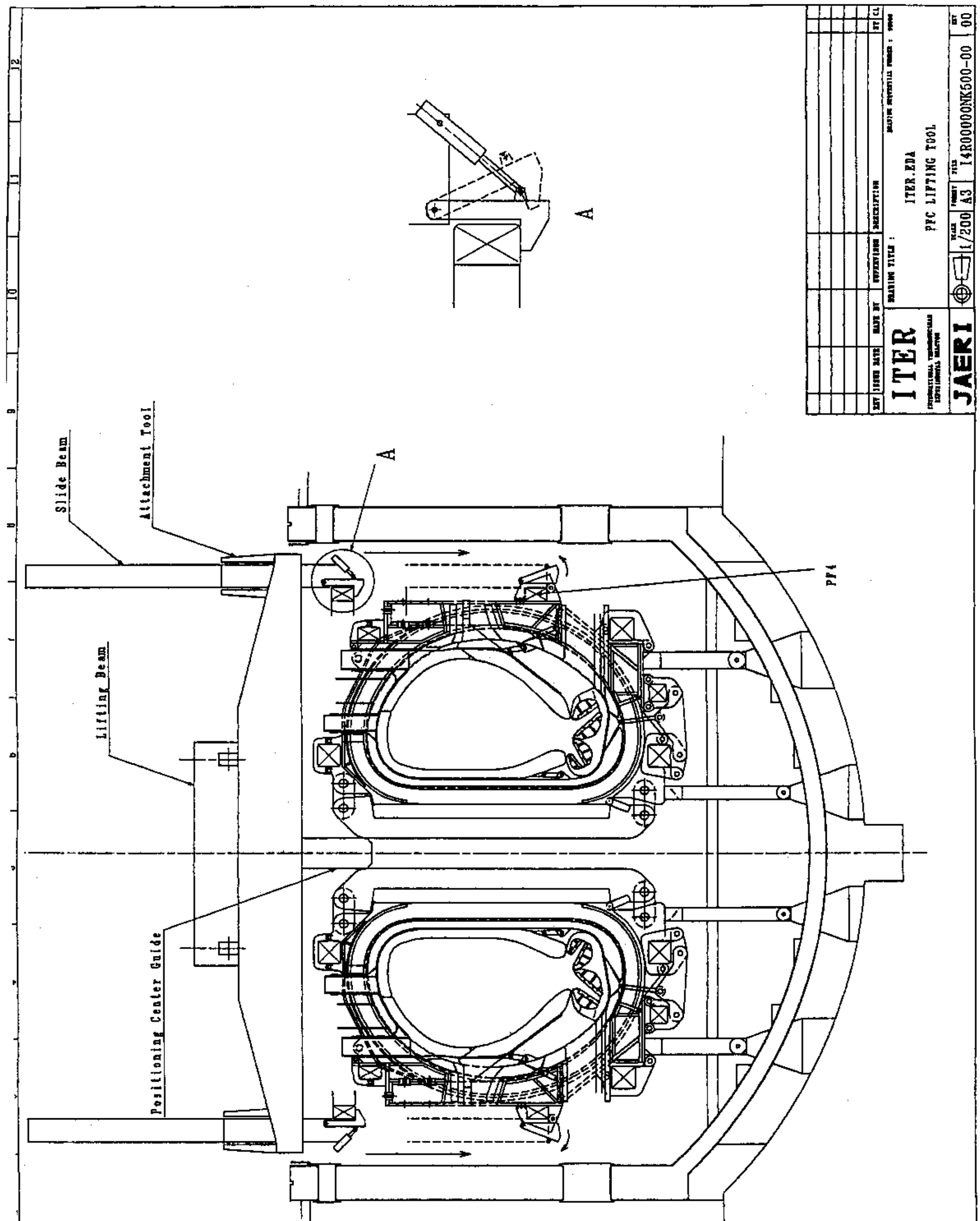

Fig. 9 PFC Lifting Tool (PFC 4)

PF Coil 5

Weight	:	745ton
Width x Height	:	ϕ27.10m x 1.27m
Lifting Point	:	18 Point
Lifting Method	:	Hole Catch
Positioning Device	:	Mechanical Type
Detecting Device	:	Position Detecting Device
		Inclinometer Device
		Acceleration Detecting Device

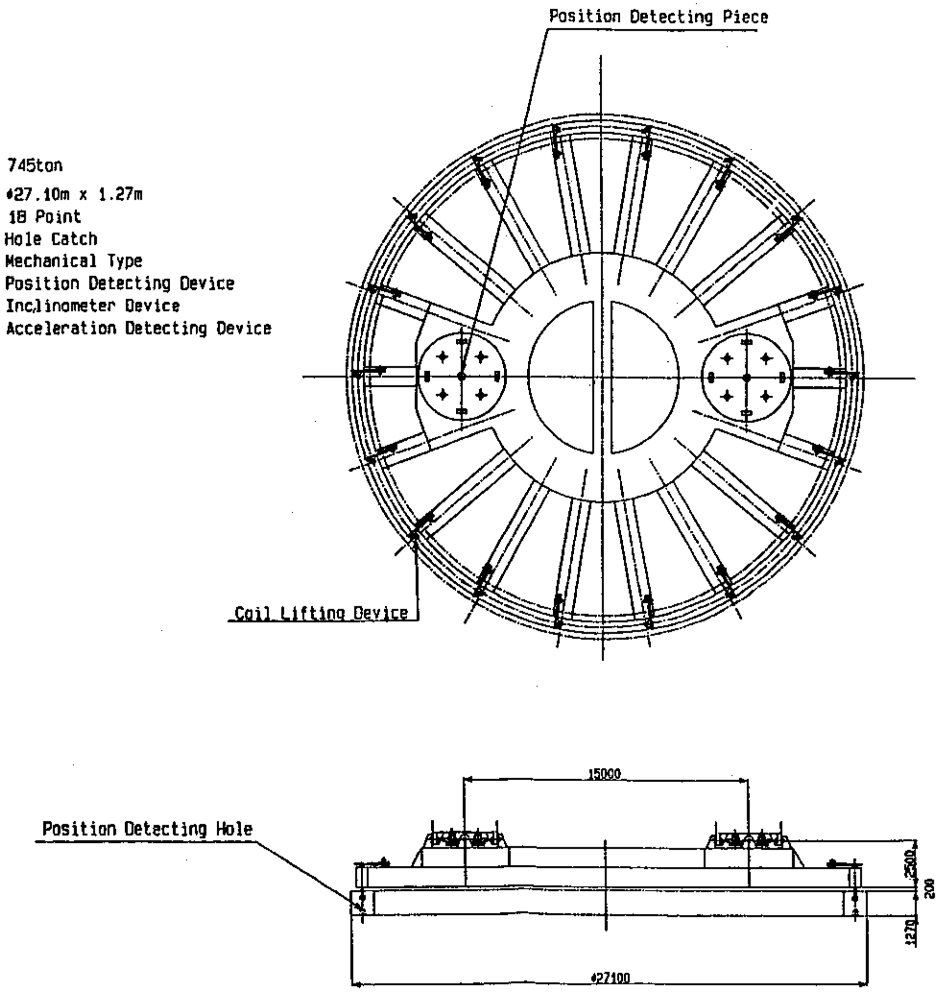

Fig. 10 PFC Lifting Tool (PFC 5)

PF Coil 6

Weight	:	285ton
Width x Height	:	φ19.60m x 0.90m
Lifting Point	:	12Point
Lifting Method	:	Hole Catch
Positioning Device	:	Mechanical Type
Detecting Device	:	Position Detecting Device
		Inclinometer Device
		Acceleration Detecting Device

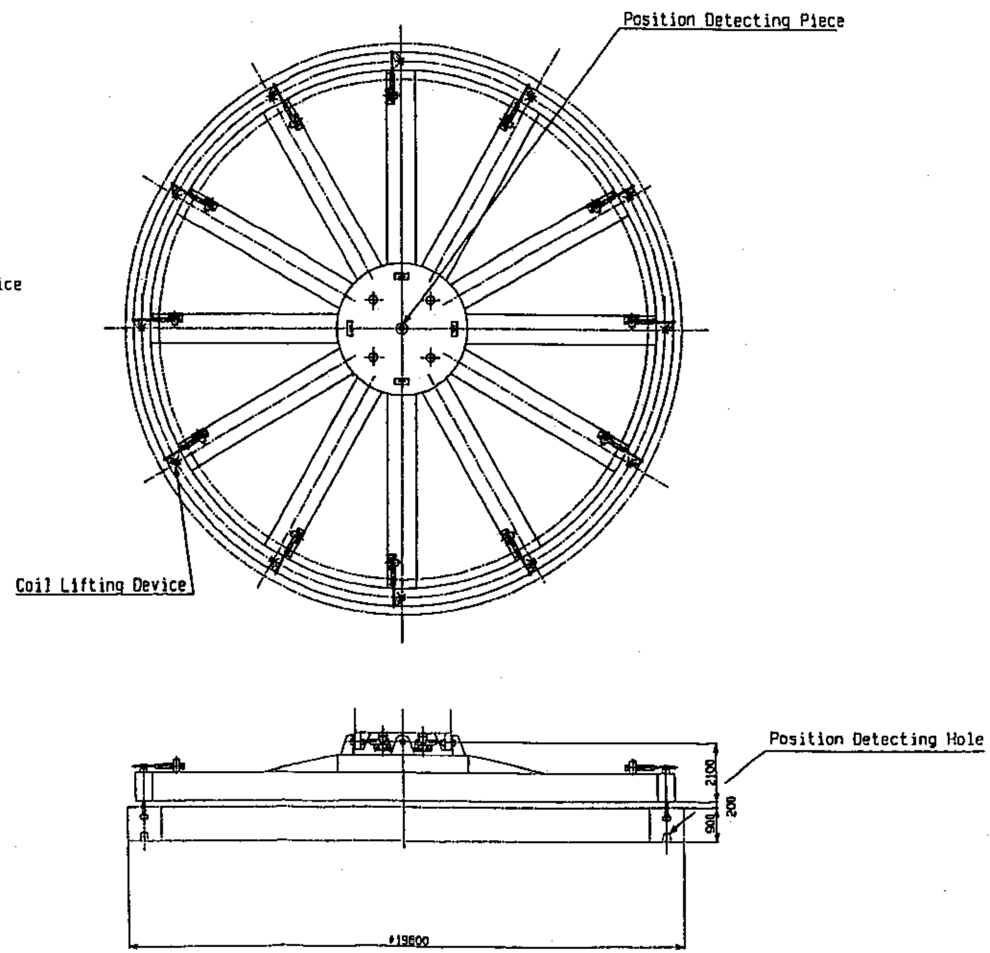

Fig. 11 PFC Lifting Tool (PFC 6)

PF Coil 7

Weight	:	311ton
Width x Height	:	ϕ12.66m x 1.2m
Lifting Point	:	12Point
Lifting Method	:	Hole Catch
Positioning Device	:	Mechanical Type
Detecting Device	:	Position Detecting Device
		Inclinometer Device
		Acceleration Detecting Device

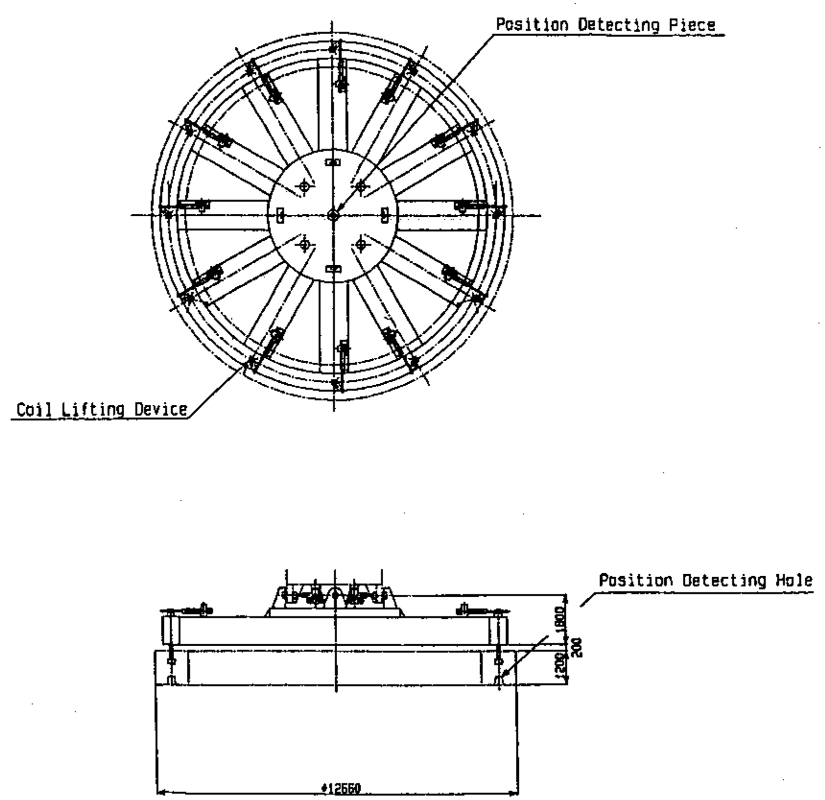

Fig. 12 PFC Lifting Tool (PFC 7)

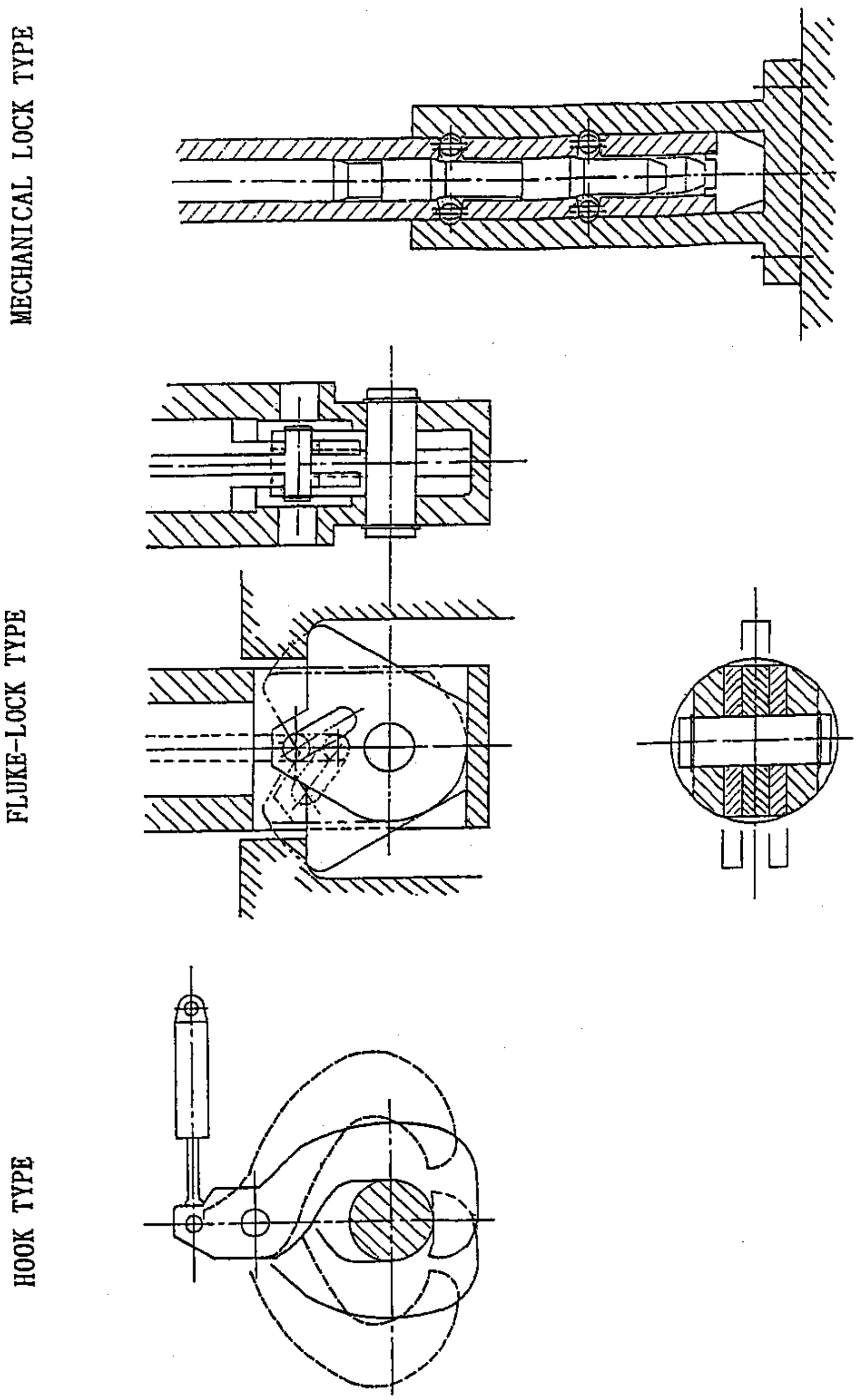

Fig. 13 Connection Heads

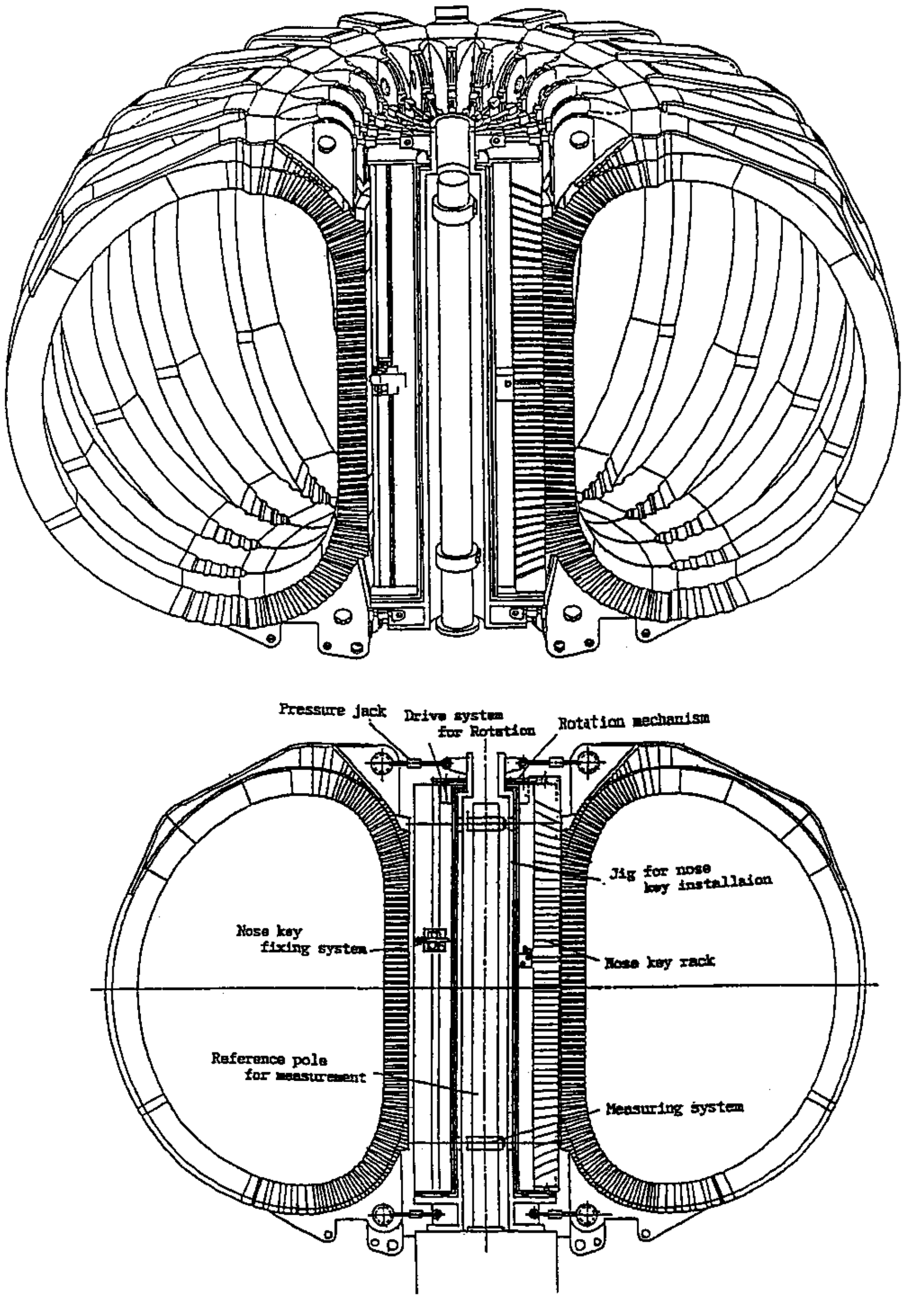

Fig. 14 Plan View of Nose Key Installation System

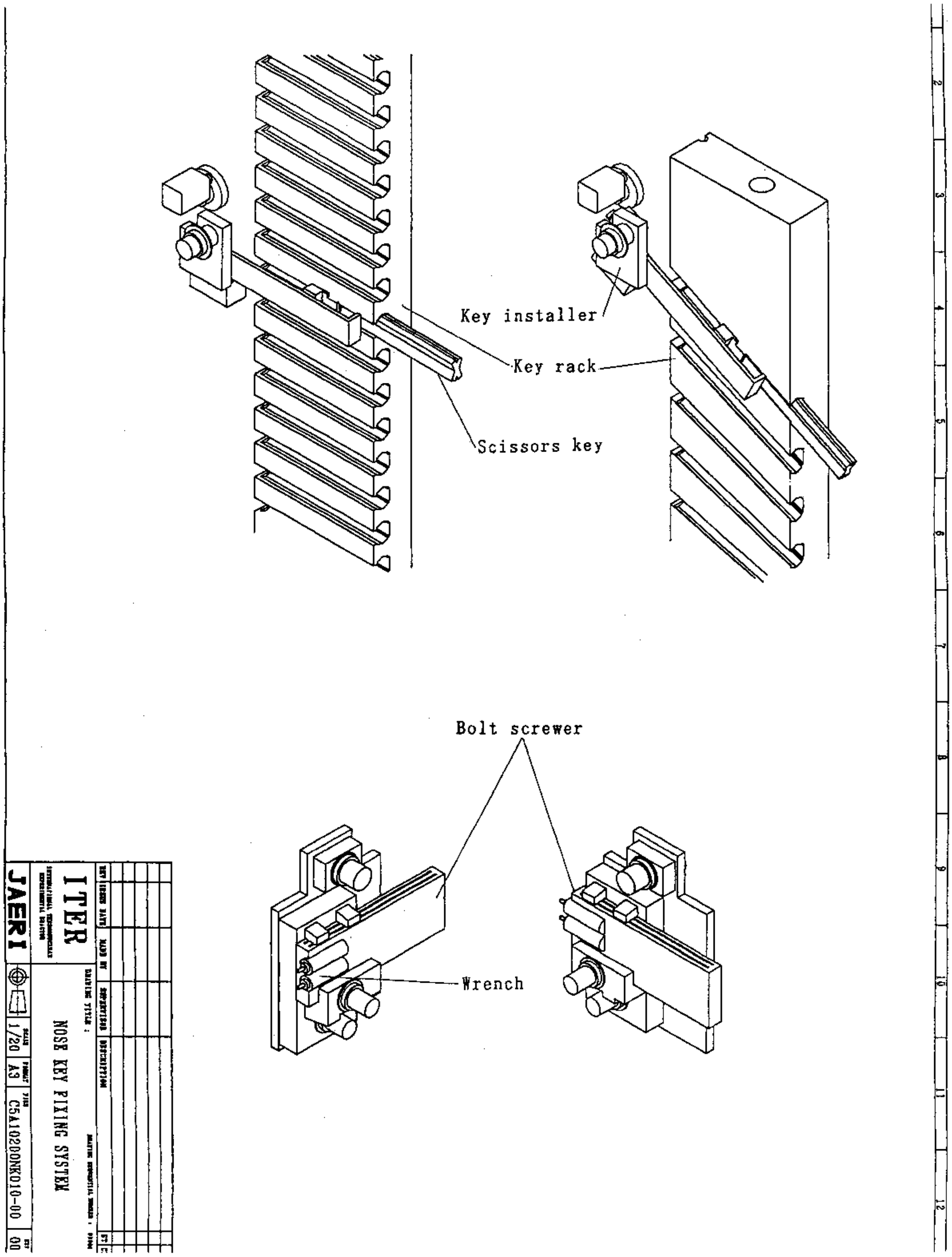

Fig. 15 Nose Key Installation Tool

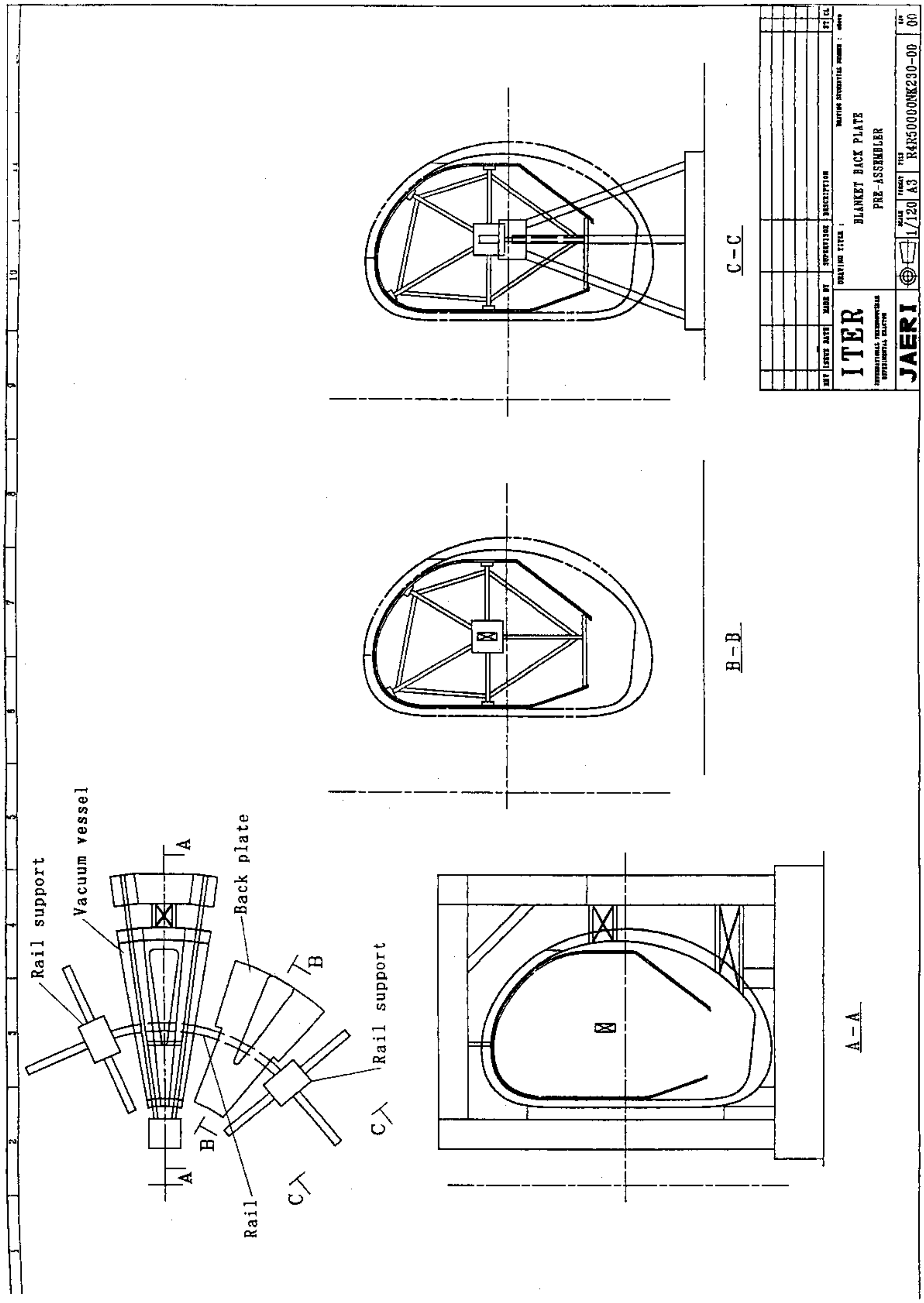

Fig. 16 VV Pre-assembly Tool

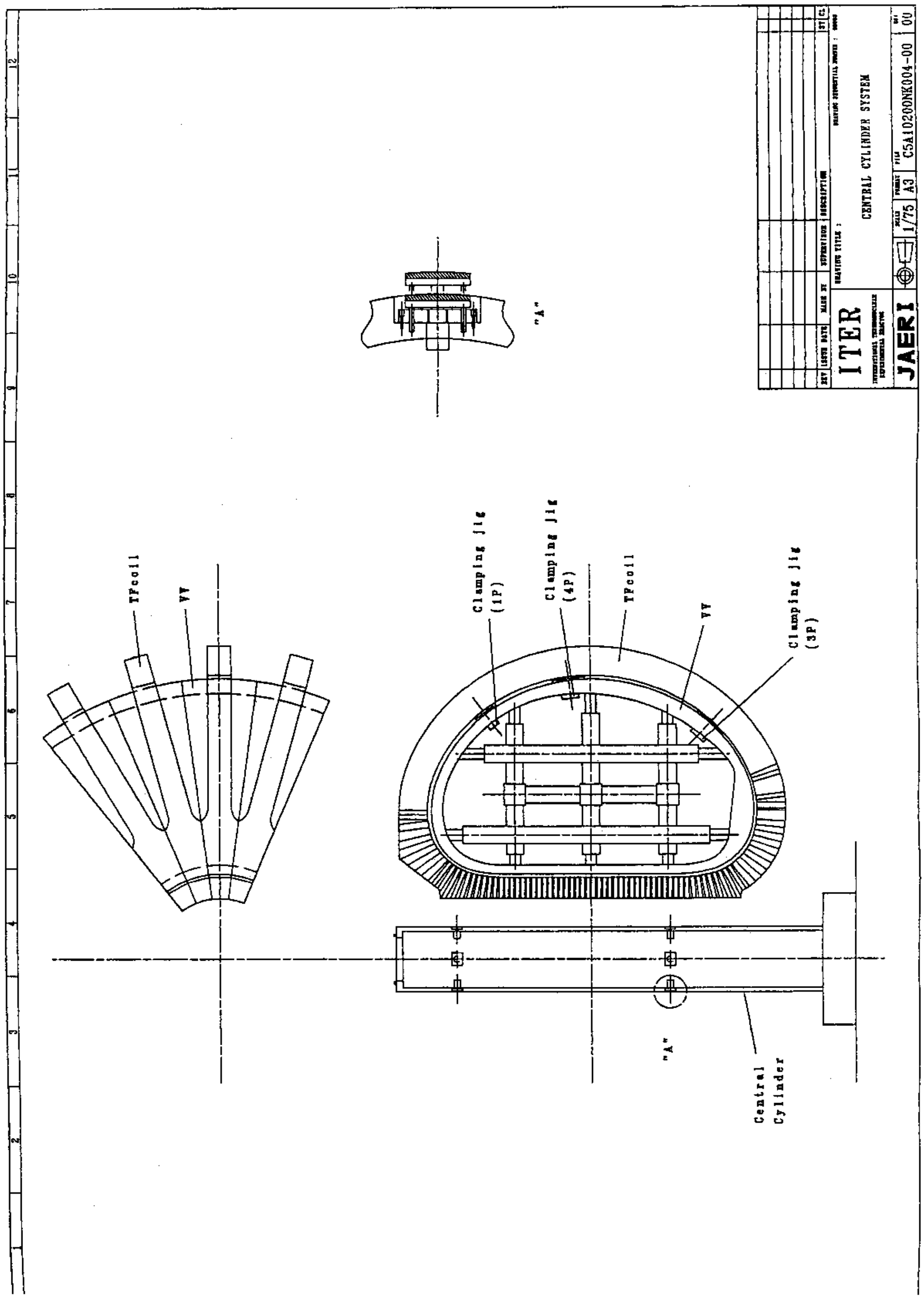

Fig. 17a Central Fixture

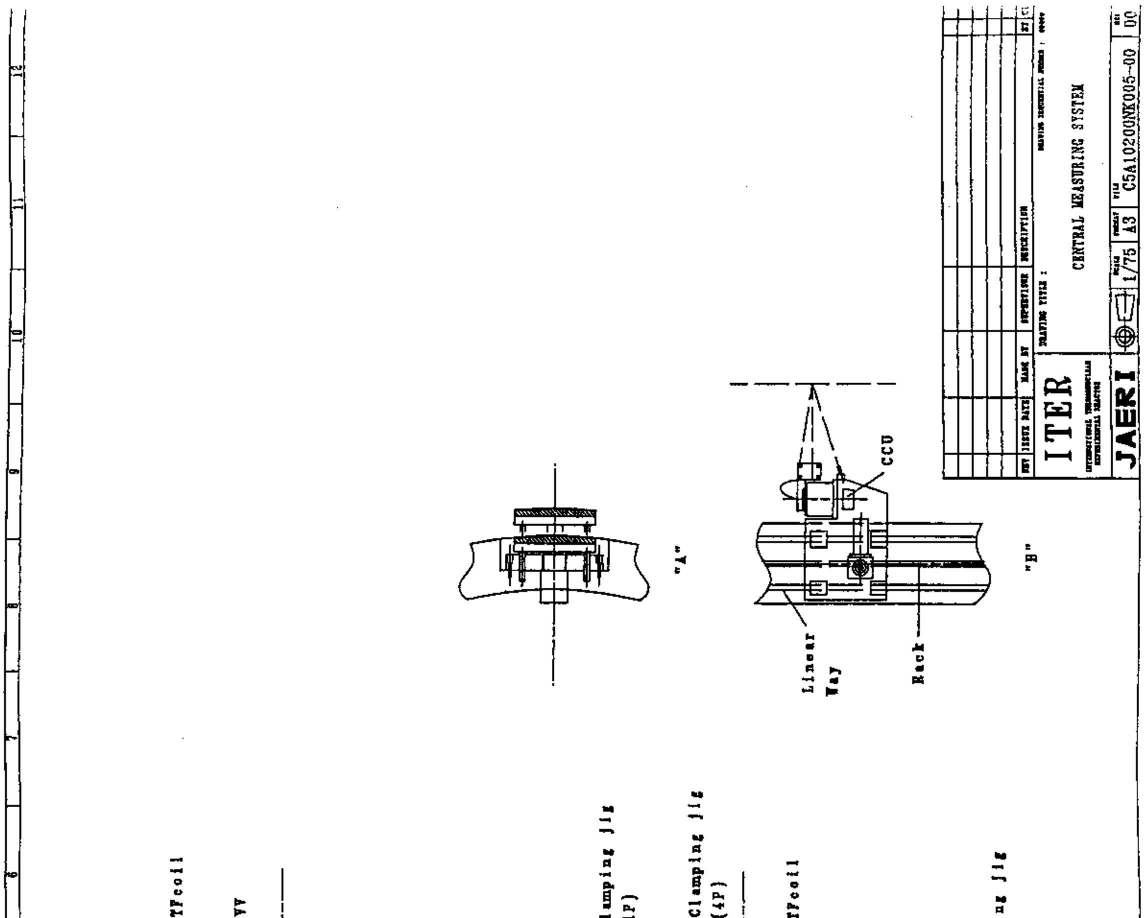

Fig. 17b Central Measuring System