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**CRITICAL ELEMENT DEVELOPMENT OF STANDARD
PIPE CONNECTOR FOR REMOTE HANDLING**

August 1994

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for Remote Handling

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(Received May 16, 1994)

In fusion experimental reactors such as ITER, the in-vessel components such as blanket and divertor are actively cooled and a large number of cooling pipes are located around the core of reactor, where personnel access is prohibited. Mechanical pipe connectors are highly required as standard components for easy and reliable connection/disconnection of cooling pipe by remote handling.

For this purpose, a clamping chain type connector has been developed with special mechanisms such as plate springs and guide structures so as to enable concentric and axial movement of clamping chain for easy mounting and dismounting. The basic performance test of a prototypical connector for a 80-A pipe shows sufficient leak tightness and proof pressure capability as well as simple connection/disconnection operation. In addition to the clamp chain type connector, design efforts have been made to develop a quick coupling type connector and a preliminary model of air-actuated quick connector has been fabricated for further investigations.

This paper gives the design concept of mechanical pipe connectors such as clamping chain type and quick coupler type, and the basic performance tests results of clamping chain type connector.

This work is conducted as a ITER Technology R&D and this report corresponds to 1993 ITER Emergency R&D Task Agreement (JB-DI-4).

* Department of ITER Project

Keywords: Fusion Experimental Reactor, Remote Handling, Mechanical Pipe
Connector, Standard Component, Clamping Chain, Quick Coupler

遠隔操作対応配管継手の開発

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(1994年5月16日受理)

核融合炉内の大型構造物であるブランケットモジュール、ダイバータモジュールの交換保守に際し、配管系を容易にかつ、高い信頼性で着脱する手法の確立は必須である。高い放射線環境下に鑑み、これらの作業は遠隔操作で行われる必要がある。

この要請に応えるためクランプチェーン型継手に着目し、改良を加える方向で開発を進めてきた。配管呼び径 80 A パイプに適応するクランプチェーン型継手において、チェーンが同心円状に開く補助機構、及びチェーンの軸方向移動の補助機構を設計・試作し、リーク試験、耐圧試験、着脱試験、及び着脱作業の再現性試験を実施し、実機適用への見通しを得た。

本報告書では、クランプチェーン型継手の詳細な設計及び基本特性試験の結果について記述する。

本作業は、国際熱核融合実験炉 (International Thermonuclear Experimental Reactor) の工学設計活動として、1993 年緊急作業契約 (JB-DI-4) に基づいて実施した。

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1. Introduction

Remote handling is an essential technology aiming at realization of fusion experimental reactors such as International Thermonuclear Experimental Reactor (ITER)[1] since the core of reactor is activated due to 14-MeV neutron and assembly/maintenance of reactor components has to be conducted remotely[2]. In particular, the in-vessel components such as blanket and divertor are actively cooled and a large number of cooling pipes located around the core of reactor where personnel access is prohibited. Accordingly, remote handling equipment to connect/disconnect cooling pipes are inevitably required for assembling/disassembling the in-vessel components in case of unexpected failure.

For this purpose, the Japan Atomic Energy Research Institute (JAERI) has been developing a pipe connector which satisfy vacuum leak tightness under nuclear and high temperature environments as well as easy connection and disconnection by remote handling. In addition, international collaboration efforts have been made through the framework of Engineering Design Activity (EDA) of ITER and a mechanical pipe connector development has been engaged in close contact with the ITER Joint Central Team (JCT).

This paper gives the design concept of mechanical pipe connectors and the basic performance test results of a clamping chain type connector which has been developed according to the 1993 ITER Emergency R&D Task Agreement (JB-DI-4).

2. General approach for pipe connector development

2.1 Design requirements

In the core of reactor, actively cooled in-vessel components such as blanket and divertor are located inside the plasma vacuum vessel which is to maintain high vacuum for plasma and to be a sound containment of tritium in terms of safety. A large number of cooling pipes connected to the in-vessel components are penetrated through port openings of the vacuum vessel and lead to the cooling system. Figure 1 shows typical arrangement of blanket cooling pipes in the upper vertical port region. A number of pipes with different sizes up to around 200 mm are vertically arranged. In order to assemble and replace the blanket module for the maintenance purpose, the pipes have to be connected/disconnected near the blanket module where pipe connections will be installed.

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Table 1 shows tentative design parameters chosen for pipe connection. Specifically, the pipe connector has to meet radiation resistance of around 10^7 R/h, high temperature operation typically over 100°C , leak tightness of less than 10^{-6} Pam³/s under the internal/external pressure of 10 bar/vacuum. In addition, easy connection and disconnection using remote manipulators in 2 hands is essentially requested.

Table 1 Design parameters of pipe connection

Items	Unit	Specifications
Internal operating pressure	bar	10
Proof pressure	bar	15
Operating temperature	$^\circ\text{C}$	100
External operating pressure	Pa	10^{-4}
Leak tightness	Pam ³ /s	10^{-6}
Radiation dose rate	R/h	$\sim 10^7$
Typical diameter of pipes	mm	100 ~ 200

2.2 Connection/disconnection mechanism

In general, a number of pipes can be gathered into an assembly unit which can be connected and disconnected at once like a cassette type connector. This concept gives advantages on remote operation due to its quickness but in the reality big concern with reliability of seal mechanism which has to provide leak tightness of a number of pipes at the same time by one connection. In addition, adjusting mechanisms for misalignment and thermal deformation of each pipe have to be feasible. Accordingly, a single pipe connector in each pipe has been selected as a primary connection method and the technology development is being conducted. However, in parallel with the single connector development, design efforts for the cassette type connection are taken into consideration.

Various types of mechanical connector are commercially available in industrial use, as shown in Fig. 2.; their features are summarized in Table 2 together with comparison from the standpoint of remote handling for fusion application.

(1) Flange type connector

A flange type connector is used in many plants and reliability has been well qualified for various sizes of pipe. However, in terms of remote handling, it requires complex operation, many tools and end-effectors as well as large

Table 2 Various pipe connection methods

	Type of connection	Connection/seal method	Disconnection	Merit	Demerit	Maintainability	Remarks
1	Welding	<ul style="list-style-type: none"> • Welding connection 	<ul style="list-style-type: none"> • Disconnection by machining or arc cutting 	<ul style="list-style-type: none"> • High reliably. 	<ul style="list-style-type: none"> • Large space • Complex alignment • Less repeatability 	C	
2	Flange	<ul style="list-style-type: none"> • Bolt fastening • Seal gasket or O ring 	<ul style="list-style-type: none"> • Unscrew of bolts 	Same as above	<ul style="list-style-type: none"> • Complex operation • Large space 	C	
3	Quick coupler	<ul style="list-style-type: none"> • Cap nut fastening • Seal gasket, O ring or plastic deformation 	<ul style="list-style-type: none"> • Unscrew of cap nut 	<ul style="list-style-type: none"> • Quickness 	<ul style="list-style-type: none"> • Large torque • Scalability 	B	<ul style="list-style-type: none"> • Swage lock limited up to 2B size
4	Clamp chain	<ul style="list-style-type: none"> • Fastening of clamping chain • Seal gasket or O ring 	<ul style="list-style-type: none"> • Unscrew of clamping chain bolt 	<ul style="list-style-type: none"> • Simple operation 	<ul style="list-style-type: none"> • Scalability 	A	<ul style="list-style-type: none"> • Enough experience up to 24B size
5	Shape memorial alloy	<ul style="list-style-type: none"> • Metallurgical transformation • Plastic deformation 	<ul style="list-style-type: none"> • Metallurgical transformation 	<ul style="list-style-type: none"> • Compactness • Simple operation 	<ul style="list-style-type: none"> • Radiation effect • Scalability 	A	<ul style="list-style-type: none"> • Less experience for industrial use

working space so as to handle several fastening bolts and washers. Therefore, it seems to be inadequate for a candidate of pipe connector in this specific application.

(2) Quick coupler type connector

In case of Swage lock type connector, large torque to fasten a cap nut is required a remote handling system. In addition, reliability of seal characteristics is concerned a large size of pipe connection. In fact, the maximum size of Swage lock is limited to be 2B for commercial use.

As for other types of quick coupler, design investigations have been conducted so as to develop reliable mechanism applicable to a large size of pipe connection. As a result, two types of quick coupler are proposed; one is an air-actuated quick connector which has been experienced in cooling water connection up to 200-mm diameter. For fusion application, design modifications are necessary so as to improve radiation hardness and vacuum tightness. A preliminary model of air-actuated connector with a pipe diameter of 150 mm has been fabricated for further performance tests, as shown in Fig. 3 and 4. Another concept is a plug type coupler so as to enable connection and disconnection in a single motion, as shown in Fig. 5. For both of quick couplers, further investigations are necessary.

(3) Shape memorial alloy type connector

The pipe connection with shape memorial alloy gives simple and compact connection/disconnection. However, in case of shape memorial alloy type connector, effect of radiation on the metallurgical transformation is not well qualified. At present, characterization of shape memorial alloy under radiation conditions are being planned.

(4) Clamping chain type connector

A clamping chain type connector provides relatively simple and compact pipe connection/disconnection and gives advantage for use of a large size pipe compared with a quick coupler type connector. As a whole, a clamping chain type connector seems to be a primary candidate for connection/disconnection of cooling pipe of the in-vessel components. A prototypical connector with clamping chain has been fabricated and the basic feasibility has been demonstrated through basic performance tests such as cyclic connection/disconnection, leak tightness and proof pressure.

3. Design features of clamping chain type connector

Detailed design of a 80-A pipe connector with clamping chain has been developed and a prototypical connector has been fabricated. Figures 6 and 7 shows detailed structure and external view of the clamping chain type connector fabricated, respectively. In the process of the design and fabrication of this connector, efforts have been made to achieve compactness, simple remote operation and effective seal performance with small fastening torque of clamping chain bolt. The major parameters of this clamping chain type of connector are listed in Table 3 and the key features are as follows.

- (1) Plate springs divided into three pieces are inserted to the clamping chain so as to enable reliable mounting/dismounting of the clamping chain; in this configuration, the clamping chain can be opened/closed with concentric motion in the radial direction by simple screwing of the clamping chain bolt. In addition, uniform compression on seal surface can be expected due to reinforcement of clamping with plate spring.
- (2) The clamping chain is enveloped in a guide casing which is connected to a halves of pipe and can slide in the axial direction for along the pipe outer surface for connection/disconnection without any interference, resulting in simple manipulation by remote handling.
- (3) Typical operation for pipe connection is as follows;
 - a. Set a seal gasket in edge groove of a halves of pipe
 - b. Align another halves of pipe on the seal edge plane
 - c. Move the guide casing with clamping chain to a connection position
 - d. Screw the clamping chain bolt

Figure 7 shows a schematic view of end-effector and tools designed for handling this clamping chain type connector.

Table 3 Major parameters of 80-A clamping chain type connector

Items	Unit	Specifications
Inner operating pressure	bar	10
Leak tightness	Pam ³ /s	10 ⁻⁶
Pipe diameter (80-A)	mm	89.1 outer dia.
Guide casing diameter	mm	200
Size of clamping chain bolt		M8 (8 mm dia.)
Fastening torque of bolt	N-m	10
Compression force on seal surface	kN	15.5
Seal gasket		Al (Type TJ80)

The size of clamping chain bolt can be defined by design pressure of coolant flowing inside the pipe. Table 4 shows the relation between the fastening forces and allowable internal pressure as a function of size of clamping chain bolt. The design pressure of this connector is specified to be 10 bar, so that M8 bolt gives sufficient strength against the proof pressure which is normally 1.5 times of the design value.

Table 4 Relation between bolt size and allowable internal pressure

Size of bolt	Compression on seal surface (kN)	Allowable internal pressure (bar)
M6	8.05	9.6
M8	14.7	16.0
M10	23.3	22.7
M12	34.0	29.3

Table 5 shows the relation between fastening torque of clamping chain bolt and compression force on the seal surface. In this calculation, a friction factor of 0.15 is assumed at an interface between clamping chain and flange surface. Based on this, the design fastening torque is specified to be 10 N-m which corresponds to the compression force of 15.5 kN; this provides sufficient mechanical strength to meet the proof pressure requirements as listed in Table 4.

Table 5 Relation between fastening torque and compression on seal surface

Fastening torque	Compression force
8 N-m	12.4 kN
10 N-m	15.5 kN
12 N-m	18.6 kN

4. Test results of clamping chain type connector

The basic performance tests of a prototype connector have been conducted and key characteristics such as compression pressure on the seal surface, plastic deformation of seal gasket as a function of fastening force and leak tightness are measured. As a result, the basic feasibility of clamping chain type connector has been demonstrated, including quantitative assessment comparing with design analysis.

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4.1 Compression pressure on seal surface

A pre-scale sheet with a thickness of 3 mm is set on the seal surface between flange connection and profile of compression pressure along the seal surface is measured at a 8 N-m fastening torque of clamping chain bolt. Table 6 show the measured average compression pressure comparing with the design value and compression distribution on the seal surface, respectively. It is concluded that the clamping chain provides uniform compression on the seal surface and the average compression pressure is in good agreement with the design value.

Table 6 Average compression pressure on seal surface

	Fastening torque of clamping chain bolt	Average compression pressure on seal surface
Design value	7.9 N-m	2.5 MPa
Measured value	8.0 N-m	3.0 MPa

4.2 Plastic deformation of seal gasket

Plastic deformation characteristics of aluminum seal gasket is measured using compression testing machine as a function of heat treatment condition of the gasket and the compression test results are plotted in Fig. 9. In case of annealed aluminum, plastic deformation is around 0.17 mm at a design compression force of 15.5 KN-m which corresponds to the fastening torque of around 10 N-m. The annealing temperature and holding time are 410 °C and 1 hr, respectively on the other hand, non-annealed aluminum shows less plastic deformation due to high stiffness.

Using the prototype connector, the plastic deformation profile of seal gasket is also measured for comparison at the rated fastening torque of 10 N-m. Figure 10 shows the measured profile of plastic deformation along the perimeter of seal gasket. In case of annealed aluminum, uniform deformation of seal gasket is observed with a deviation is less than 0.04 mm for all of seal surface region. The measured average plastic deformation is around 0.15 mm which is in good agreement with the compression test results. As a result, annealed aluminum gasket shows good seal characteristics. On the contrary, non-annealed aluminum shows very small deformation of around 0.02 mm, resulting in less leak tightness.

In order to qualify suitable hardness of gasket material, Vickers

hardness tests have been conducted for both annealed and non-annealed aluminum; the average Vickers hardness of both aluminum are 40 and 110, respectively.

4.3 Cyclic connection/disconnection test

Cyclic operation of repeating connection and disconnection has been conducted in the following sequence. As a result, smooth concentric movement of clamping chain is observed and the leak tightness has been maintained after 10 times of cyclic operation.

- a. Set a seal gasket in edge groove of a halves of pipe
- b. Align another halves of pipe on the seal edge plane
- c. Move the guide casing with clamping chain to a connection position
- d. Screw the clamping chain bolt
- e. Unscrew the clamping chain bolt
- f. Move out the guide casing
- g. Remove a halves of pipe and seal gasket

4.4 Proof pressure and leak tests

The proof pressure and leak test of the clamping chain type connector have been conducted at a rated fastening torque of 10 N-m. The results show that no damage and no pressure change are observed at an internal pressure of 15 bar. An external leak at a internal pressure of 10 bar is not observed with a sensitivity of $3.8 \times 10^{-8} \text{ Pam}^3/\text{s}$ which is less than the design specification of $10^{-6} \text{ Pam}^3/\text{s}$.

5. Conclusion

- (1) The design concept of a clamping chain type pipe connector has been developed for remote connection/disconnection of cooling pipe for the in-vessel components. In this concept, plate springs are inserted into a clamping chain so as to allow concentric movement of clamping chain for easy mounting and dismounting. In addition, uniform compression on seal surface can be expected due to reinforcement of clamping with plate springs.
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- (2) Based on this design concept, a prototypical connector for a 80-A pipe has been fabricated and the basic feasibility has been demonstrated through performance tests such as cyclic operation of connection and disconnection, leak tightness and proof pressure.
- (3) Further issues are to demonstrate connecting/disconnecting operation using manipulator and to qualify scalability for 200-A pipe application.
- (4) In addition to the clamp chain type connector, design efforts have been made to develop a quick coupler type connector. A preliminary model of air-actuated quick coupler for a 150-A pipe has been fabricated and the basic performance tests such as seal tightness are being planned.

Acknowledgment

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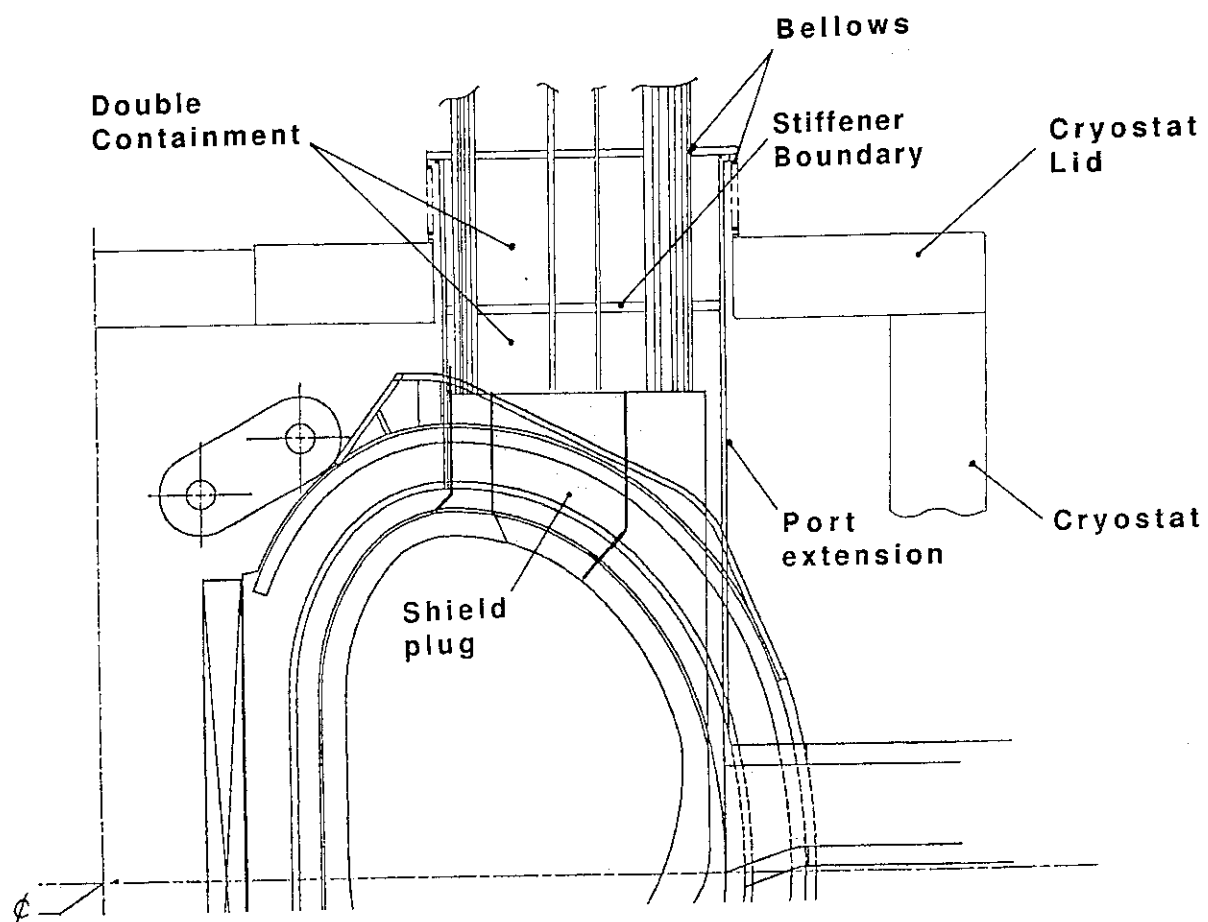
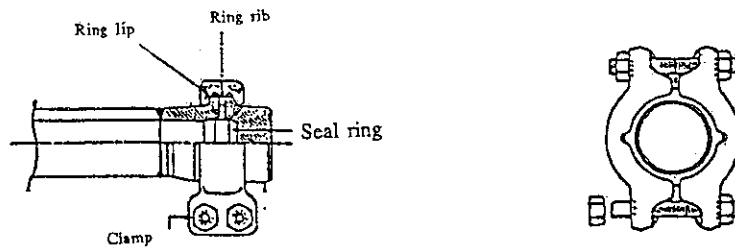


Fig. 1 Typical arrangement of blanket cooling pipe in upper vertical port region

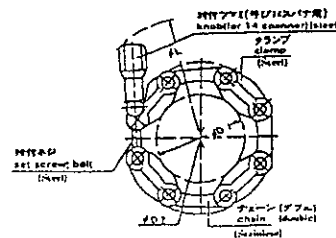
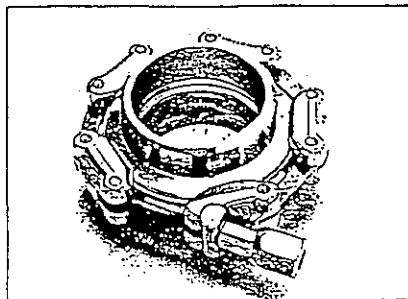
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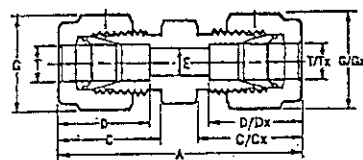
Glay lock type

クランプ・チェーンS型(アルミパッキングおよびOリング用)
Clamp Chain S-Type (for Aluminium Seals and O-Ring)

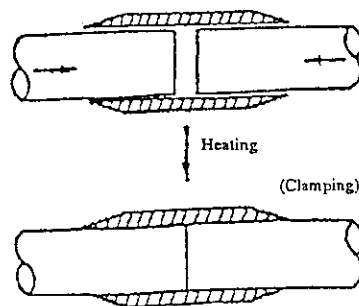
● NW10～NW63用 配管内部が加圧される時に使用します。
Can be used for additional pressure



Clamp chain type



Swage lock type



Shape memorial alloy

Fig. 2 Commercially available mechanical pipe connectors

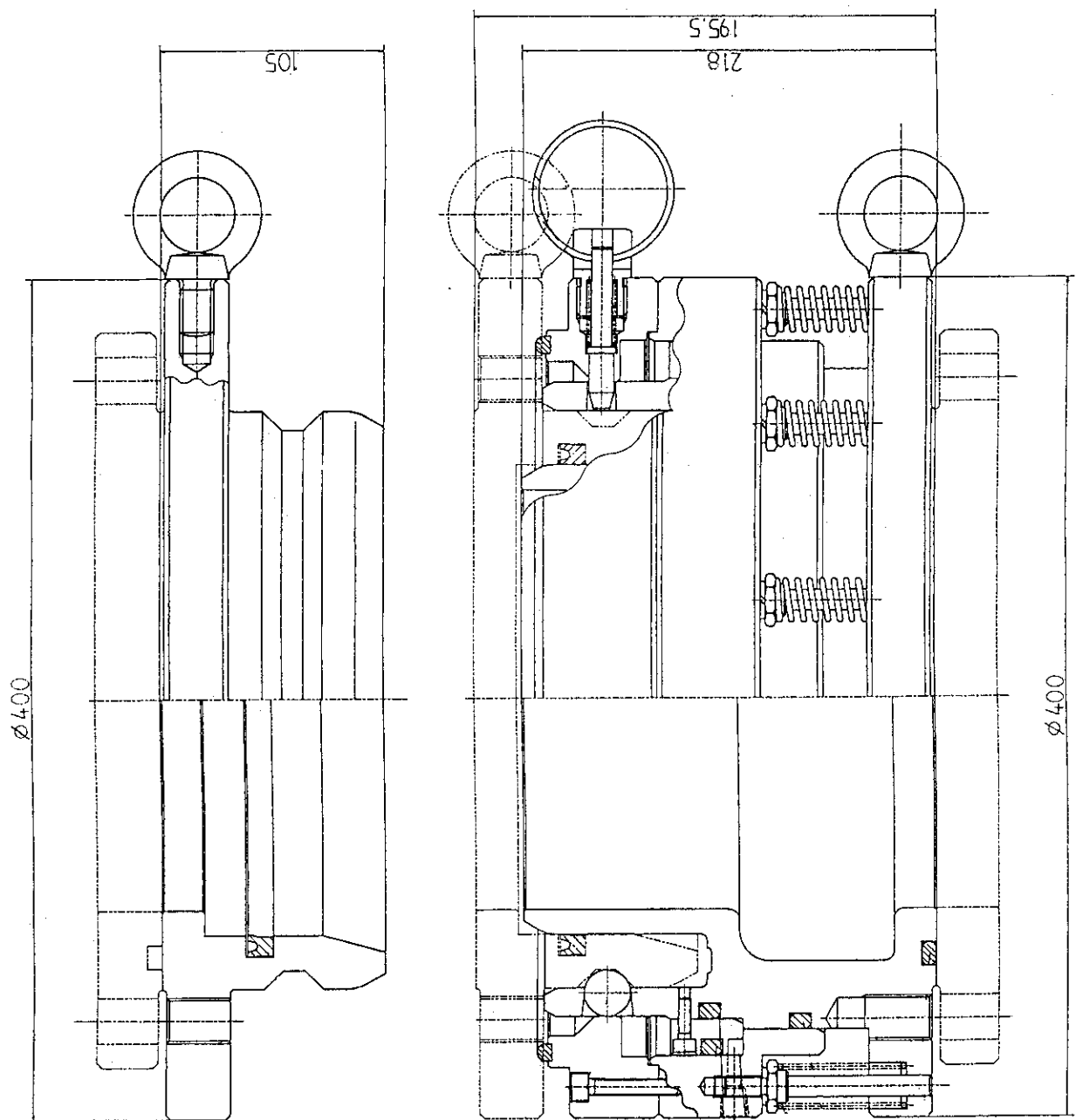
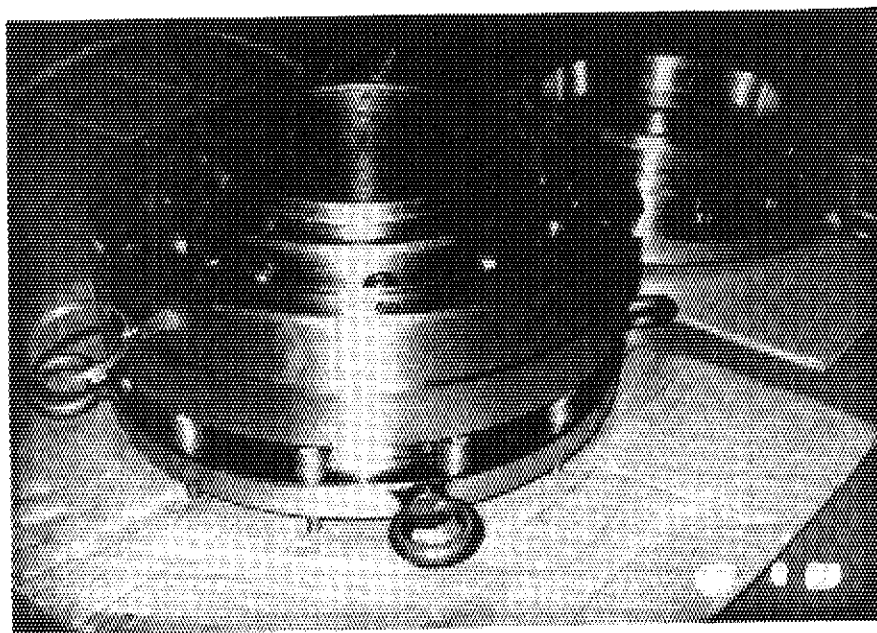
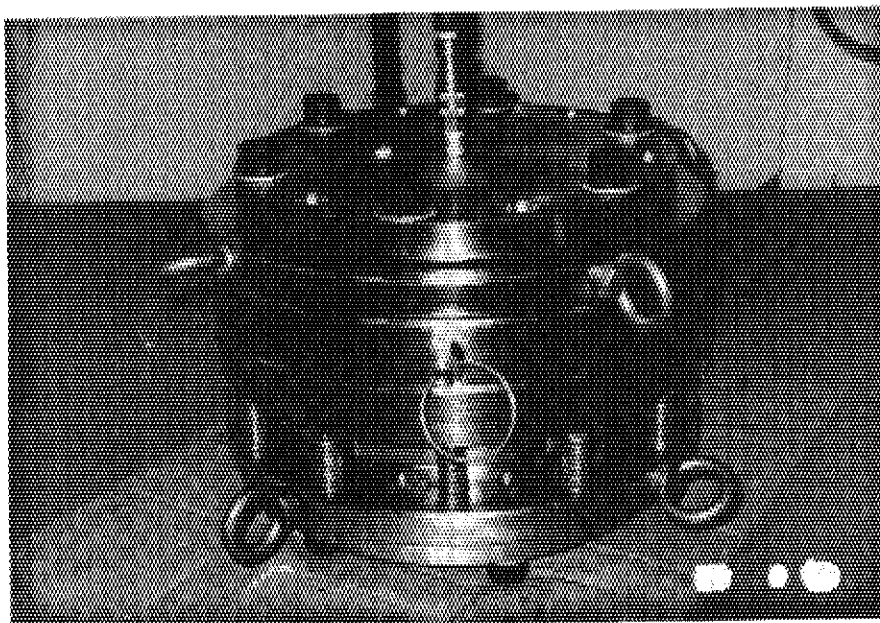


Fig. 3 Design concept of air-actuated quick coupler



Female/male connector



Assembly

Quick pipe coupler with air actuator
(Proof pressure : 30 bar , pipesize : 200-A)

Fig. 4 External view of prototype air-actuated quick coupler
for a 150-A pipe

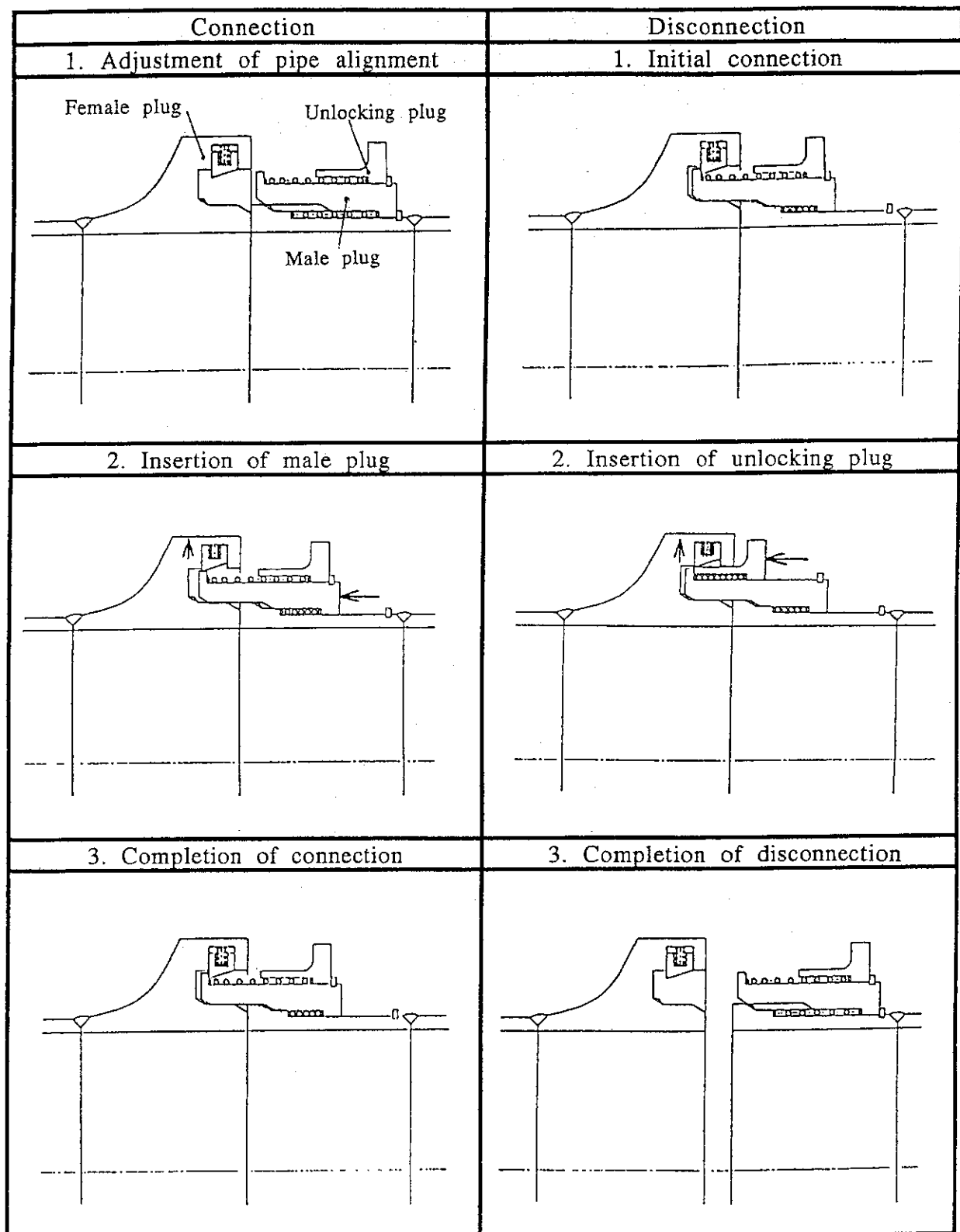


Fig. 5 Design concept of plug type quick coupler

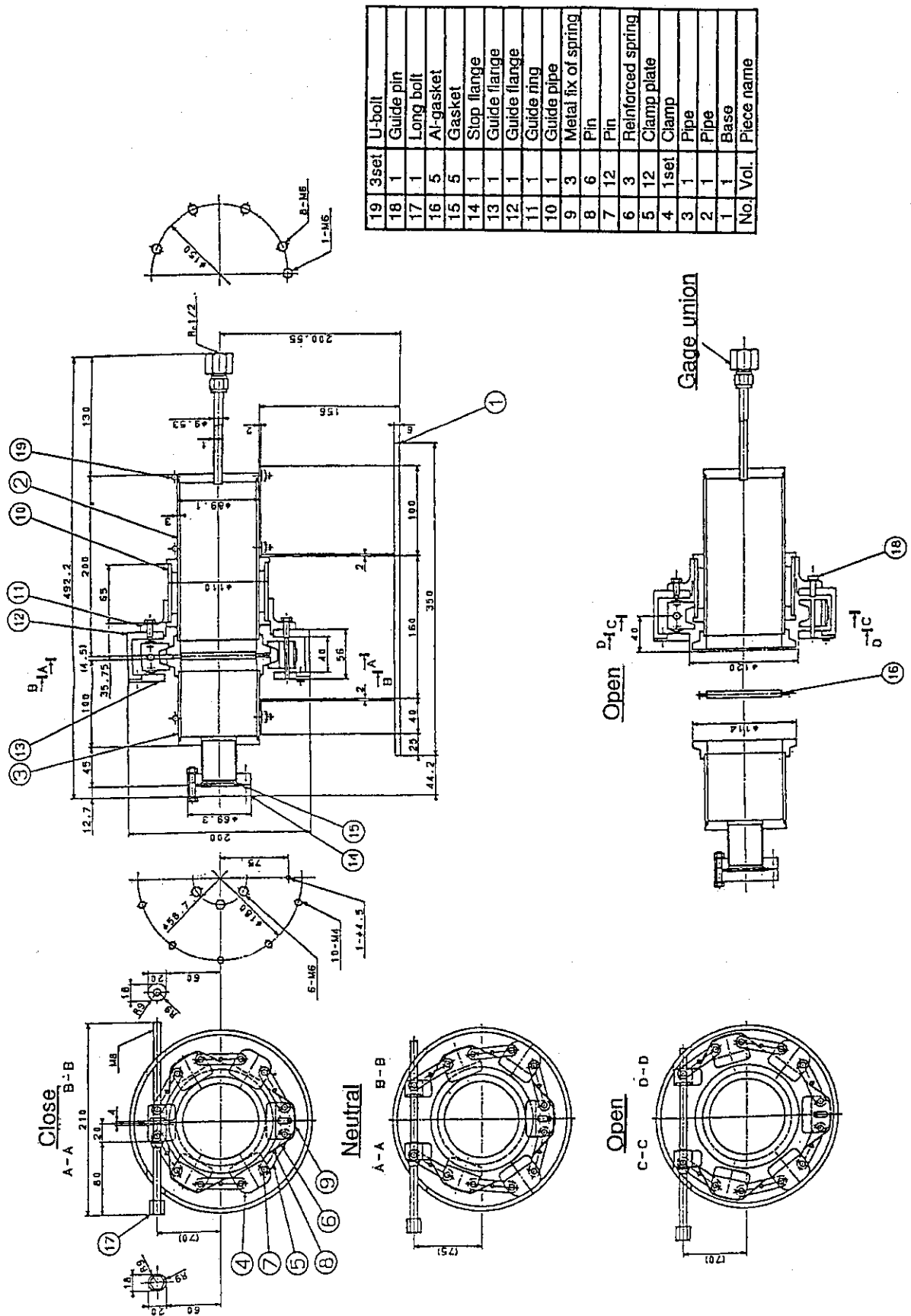
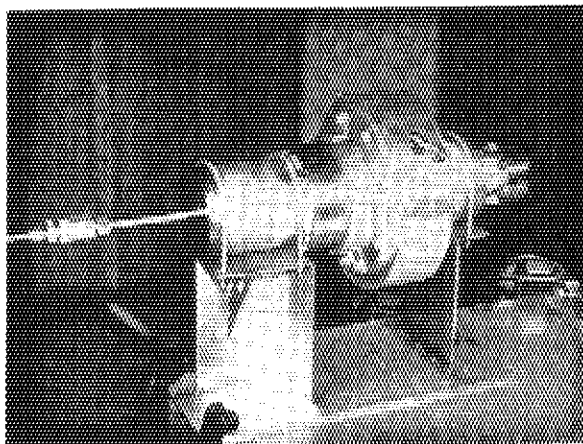
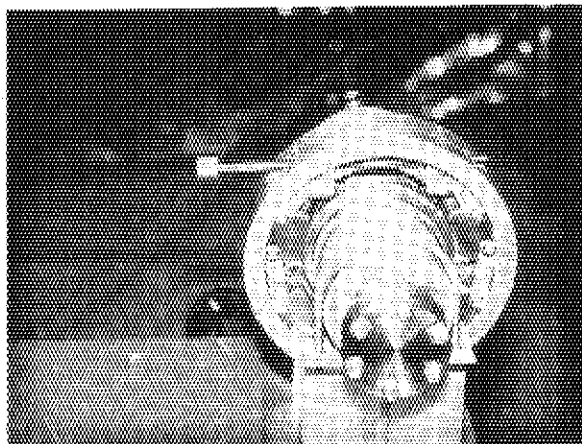


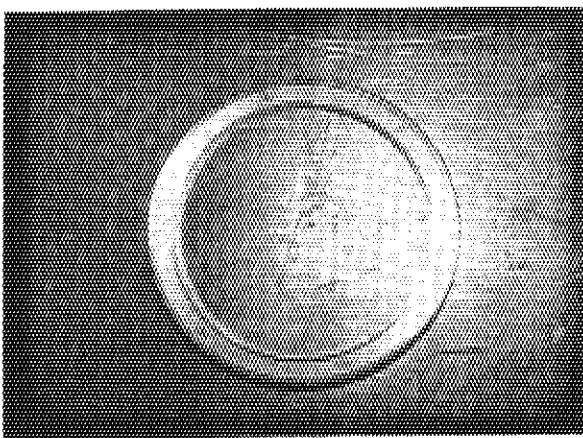
Fig. 6 Detailed structure of clamping chain type connector for a 80-A pipe



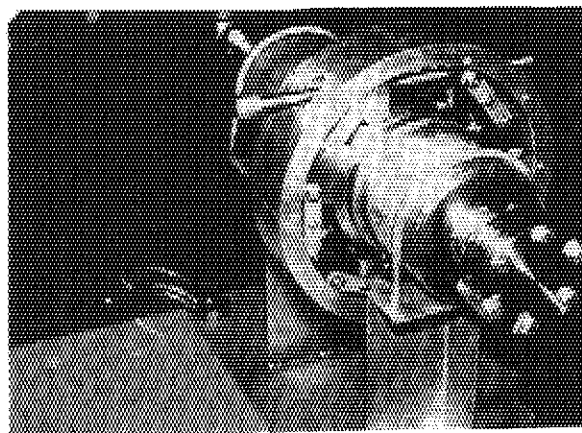
(A) Test piece



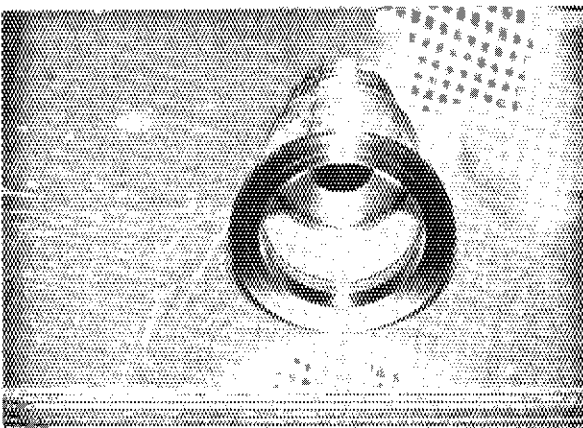
(B) Open clamp



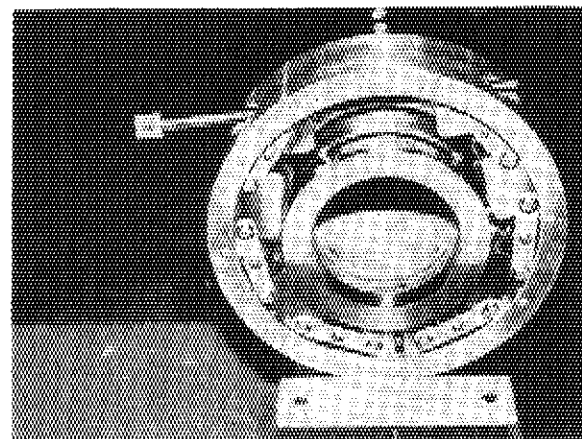
(C) Aluminum gasket (Type: TJ-80)



(D) Closed clamp



(E) Flange



(F) Disconnection

Fig. 7 External view of prototype clamping chain type connector for a 80-A pipe

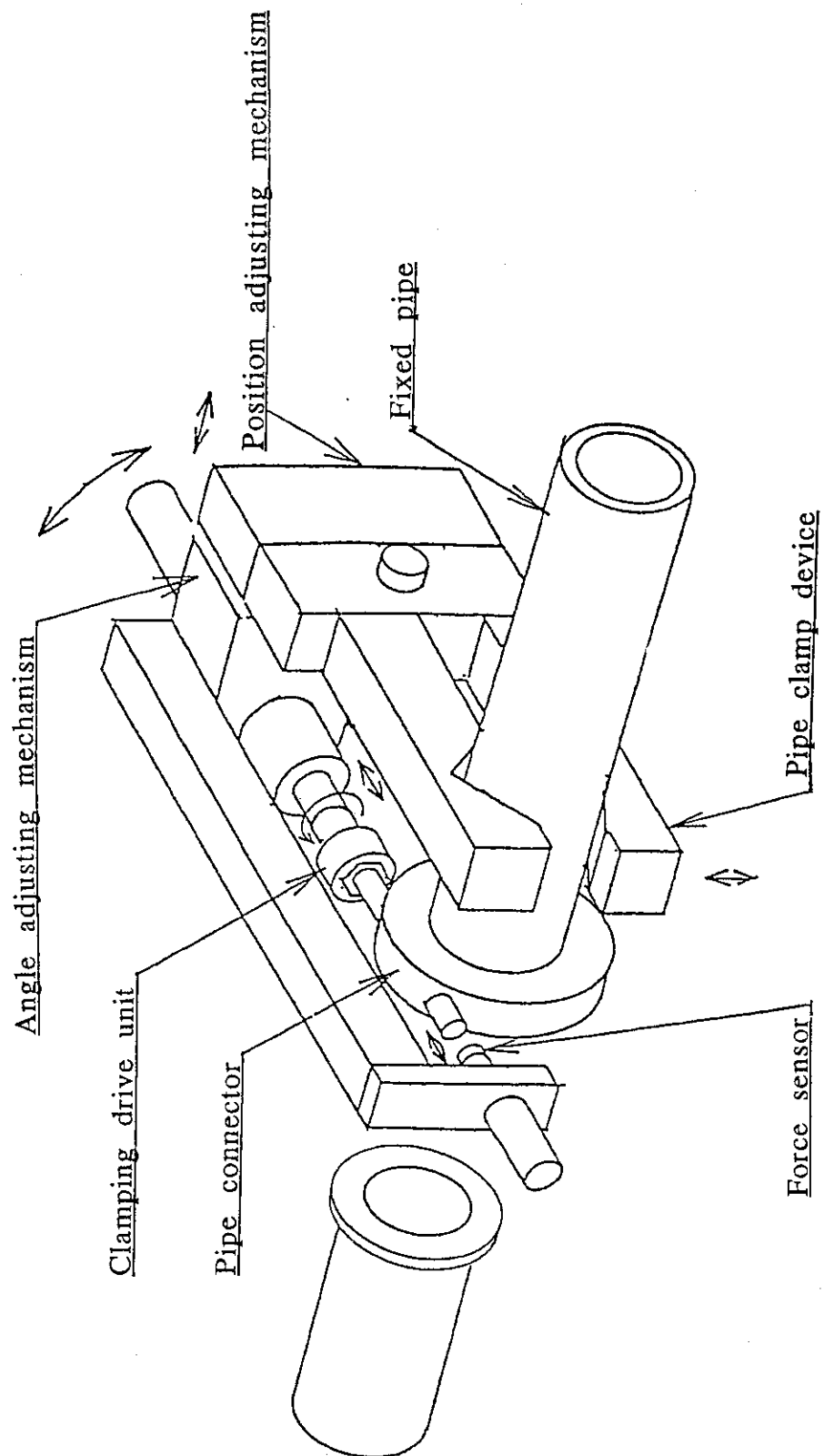


Fig. 8 Schematic plan of end-effector/tools for clamping chain type connector

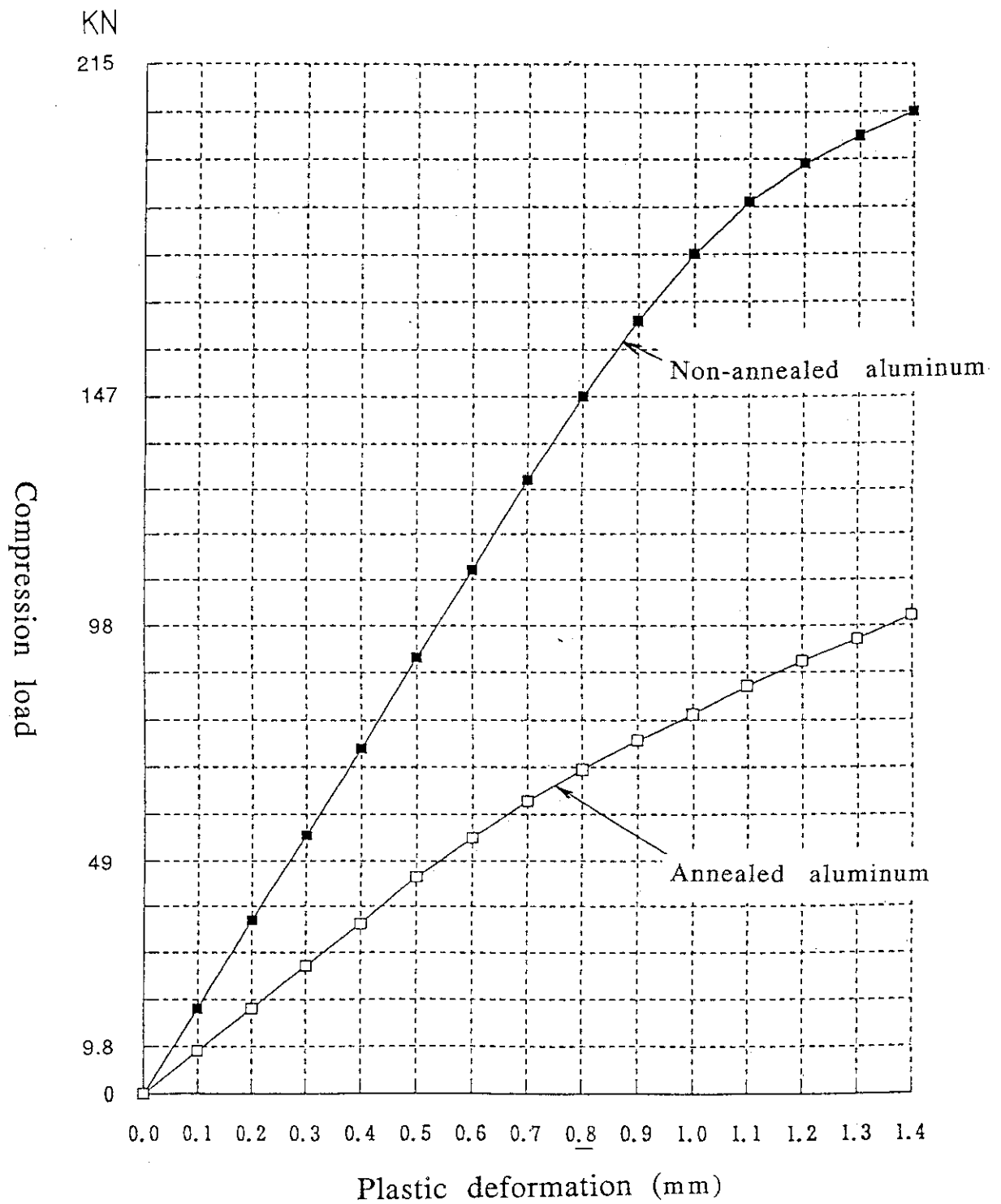


Fig. 9 Relation between plastic deformation of gasket and compression load

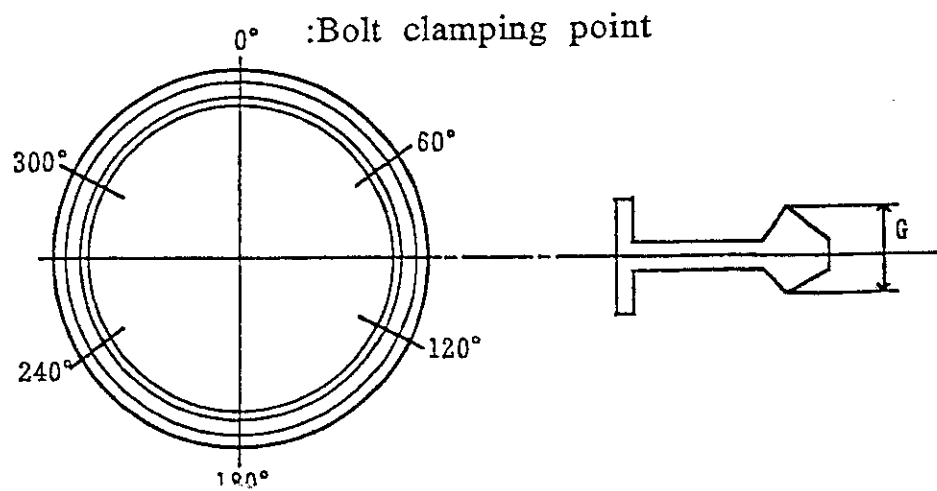
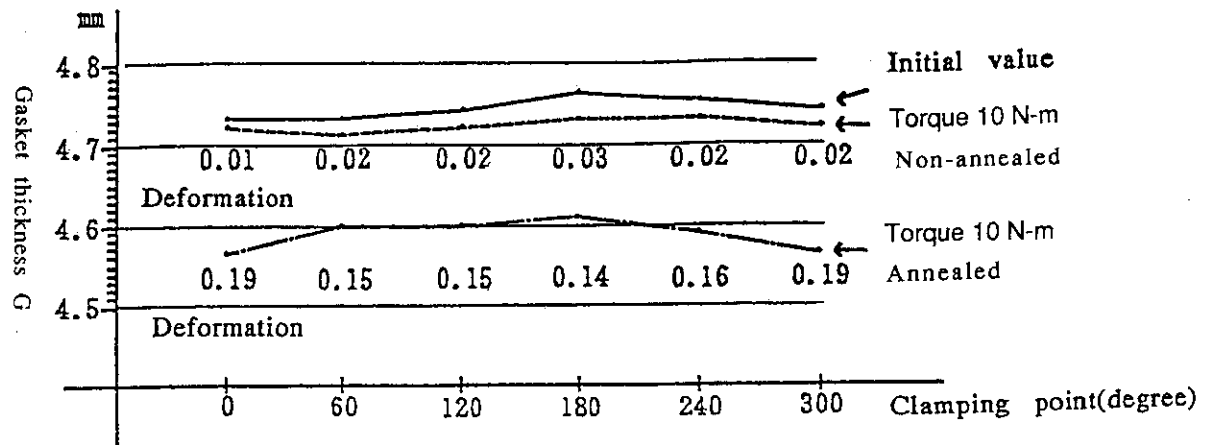


Fig. 10 Measured profile of plastic deformation along seal surface