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DEVELOPMENT OF MULTI-CHANNEL OPTICAL-FIBER FEED THROUGH FOR ITER

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Development of Multi-channel Optical-fiber Feed through for ITER

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A multi-channel fiber feed through has been developed for visible and IR transmission lines through secondary vacuum boundary (cryostat boundary) of ITER.

In the first phase, a scale down test-module which has ten fiber feed throughs in the vacuum flange was manufactured and tested. The vacuum seal was realized by soldering gold plated fibers to a vacuum flange with high temperature solder. The capacity to resist inner pressure rise of 5 atm, the acceleration resistant of 15 g and the temperature resistant from 20℃ − 200℃ were achieved by the test module. The connecting loss and the uniformity of transmission losses among each channels of the feed through were not well. Concerning the connecting loss, the best value was 2.2 dB and the worst one was 13.5 dB.

In the second phase, the full performance test-module which has 57 fiber feed throughs was manufactured and tested. The feed through was improved in order to achieve a good transmission and the uniformity among each channels by using a optical fiber implanted in a center of a quartz rod very accurately. The capacity to resist inner pressure rise of 5 atm, the acceleration resistant of 15g and the temperature resistant from 40℃ − 200℃ (Temperature ramp rate: >20℃/hr) were achieved by the full performance test-module. The connecting losses of the feed throughs were less than 3 dB, and the uniformity of transmission losses among each channels of the feed through was larger than 60%. The requirements for an optical-fiber feed through were almost satisfied with the full performance test-module.

Further developments will be necessary for the remote handling method.

Keywords : Optical Fiber, Feed Through, Multi-channel, ITER, Visible Light

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ITER用多チャンネル光ファイバー導入端子の開発

日本原子力研究所那珂研究所炉心プラズマ研究部
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（１９９８年7月２８日受理）

ITERにおける第２真空境界（クライオスタット容器壁）を通して、可視及び赤外域の光を貫通させるための多チャンネル光ファイバー導入端子と、それに対応するコネクターを開発した。

第１段階では、10チャンネルの光ファイバー導入端子を持ったスケールダウン試験モジュールを製作した。導入端子部の真空シールについては、金メッキされた光ファイバーを、高温ハンダで真空フランジに固定することにより実現した。耐圧力は５気圧まで、耐衝撃は15Gまで、温度については20度から200度までの試験に合格した。ただし、接続損失は最良で2.2dB、最も悪いもので13.5dBであり、満足いくものではなかった。

第２段階では、57チャンネルの光ファイバー導入端子を持ったフル規格モジュールを製作した。導入端子部の製作に当たっては、接続損失を減少させると同時に、そのばらつきを抑えるために、光ファイバー導入端子部の構造を改良した。具体的には、光ファイバー（コア径200μm）を精度良く中央に埋め込んだ石英ロッド（径2.5mm）を一体で製作し、そのロッドを高温ハンダで真空フランジに固定することにより接続精度を向上させた。その結果、53チャンネルの導入端子個々の接続損失がすべて３dB以下になり、チャンネル間の一様性も60%以上となった。また、耐圧力、耐衝撃に関して、それぞれ５気圧、及び15Gまでの試験に合格し、使用温度については室温から200度までの試験に合格した。さらに、真空リークについても、それぞれの試験の前後でリーク量は検出限界（5×10^{-12}pa·m^3/s）以下であった。

ITERでの要求をほぼ満足するチャンネル光ファイバー導入端子が開発できた。今後は、遠隔操作の方法について検討する必要がある。

本開発は、ITER工学R&Dの一環として行ったものであり、R&Dタスク（Task agreement number: S 55 TT 07 96-12-09 FJ, Task ID number: T347 FJ-3）に基づくものである。
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1. Introduction

In order to relay optical images from just outside the diagnostics port to the diagnostic equipment through the cryostat vacuum boundary, it will be favorable to use an optical fiber bundle in the visible and IR region. There are two advantages as follows.

i) The optical fiber bundle relays optical images through the narrow labyrinth, which is provided to prevents neutron stream, without a relay optics composed of lenses and mirrors.

ii) The problem of the displacement of the optical axis which is caused by the thermal distortion and the electromagnetic force of the diagnostic port will be evaded by using the optical fiber bundle easily.

In this situation, it is necessary to use a image transmission system through the vacuum boundary. As a one of the image transmission systems, a multi-channel optical-fiber feed through has been developed here for visible and IR light transmission lines through cryostat (second) vacuum boundary of ITER. The feed through should be designed to put the fiber bundle on it and to remove the bundle by remote control.

2. Specification

The specification of the optical-fiber feed through descrived in the work order is summarized as below.

2.1 Requirement from ITER

Material of fiber core:	Fused quartz
Diameter of fiber core:	200 μm
Number of channel:	>50
Vacuum Seal:	He Leak < 1 x 10^{-10}Pa m^3/s
Capacity to Resist Inner Pressure Rise:	>2 atm (second vacuum boundary)
Mechanical acceleration of structure:	> 15g, duration 10 ms, 1000cycles
Temperature:	20°C - 200°C
Temperature ramp rate:	> 20°C/hr,
Uniformity among each channels:	> 60 %
Maximum connecting loss per channel:	3dB

2.2 Item of R&D

-Vacuum seal method (< 1×10^{-10} Pa m^3/s)
-Fabrication of fiber connecting method (uniformity among each channels: > 60 %)
-Remote handling method

2.3 Item of Test

-Vacuum leak test:	< 1×10^{-10} Pa m^3/s
-Transmission test:	350 - 1000 nm, <3dB per channel
-Uniformity check:	> 60 %
-Capacity to Resist Inner Pressure Rise:	> 2 atm
-Temperature Resistance of up to 200 °C	with limited cycling up to 3 cycles.
-Acceleration test:	> 15g, duration 10 ms, 1000cycles
-Put on and take off test of connector:	reproducibility check

3. Developing process

The optical-fiber feed through has been developed as the task description shown in the work order.

Optical-fiber feed through has been constructed and tested according to the specifications above.

In the first phase, design of a scale down test model and the trial manufacturing was carried out in order to find out the problems.

In the second phase, the full performance test module has been fabricated. The almost problems found in the scale down test module had been solved. After the fabrication, the transmission test, the vacuum leak test, the temperature resistance test, the pressurization test and the acceleration test were carried out.

The detailed designs and the key points of the scale down test module and the full performance test module are described in the following sections.

4. Scale down test-module (first phase)

4.1 Design (Scale down test-module)

The scale down test-module has 10 fiber feed throughs on a vacuum flange. Each optical fiber plated by gold is inserted in a small SUS-pipe and soldered by the high temperature solder (sp-27), and mounted in the vacuum flange by the same solder as shown in Fig. 4.1-1. The schematic views of the optical-fiber feed through and the connector are shown in Fig. 4.1-2 and 3. The assembly view and the photograph are also shown in Fig. 4.1-4 and 5 respectively.

The specification of the scale down test-module is summarized as follows.

-Material of fiber core :	Fused quartz
-Diameter of fiber core :	200 μm
-Number of channel:	10
-Vacuum Seal Method:	Gold plated fiber + high temperature solder (sp-27)
-Capacity to Resist Inner Pressure Rise:	5 atm
-Mechanical acceleration of structure:	> 15g, duration 10 ms, 1000 cycles
-Temperature:	20°C - 200°C
-Uniformity among each channels:	60 % (target)
-Maximum connecting loss per channel:	3 dB (target)
-Connector:	Manual handling

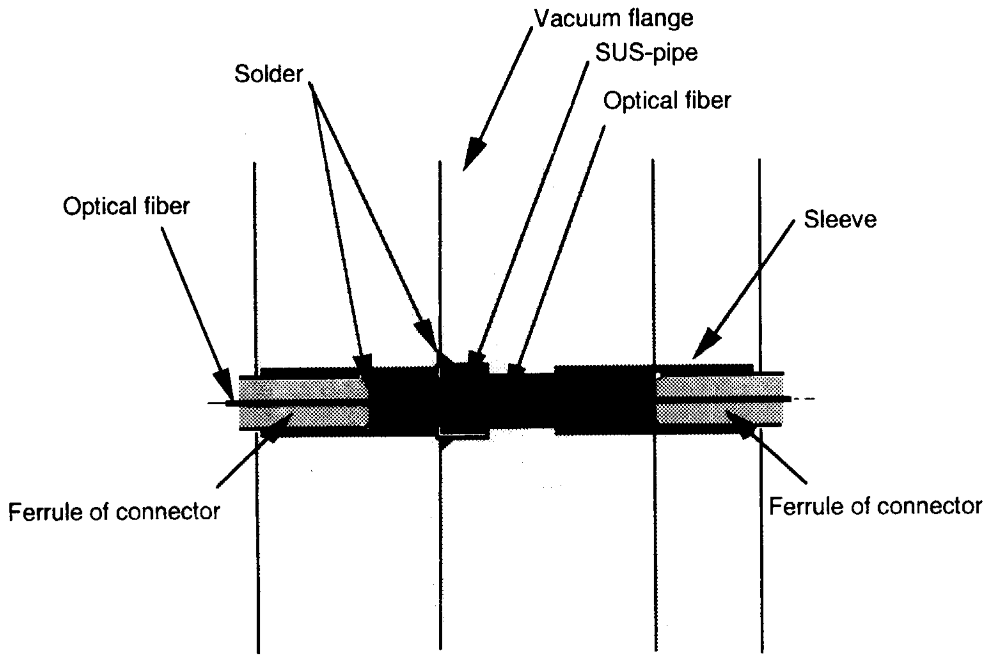


Fig. 4.1-1 Cross section view of the optical-fiber feed through (scale down test-module).

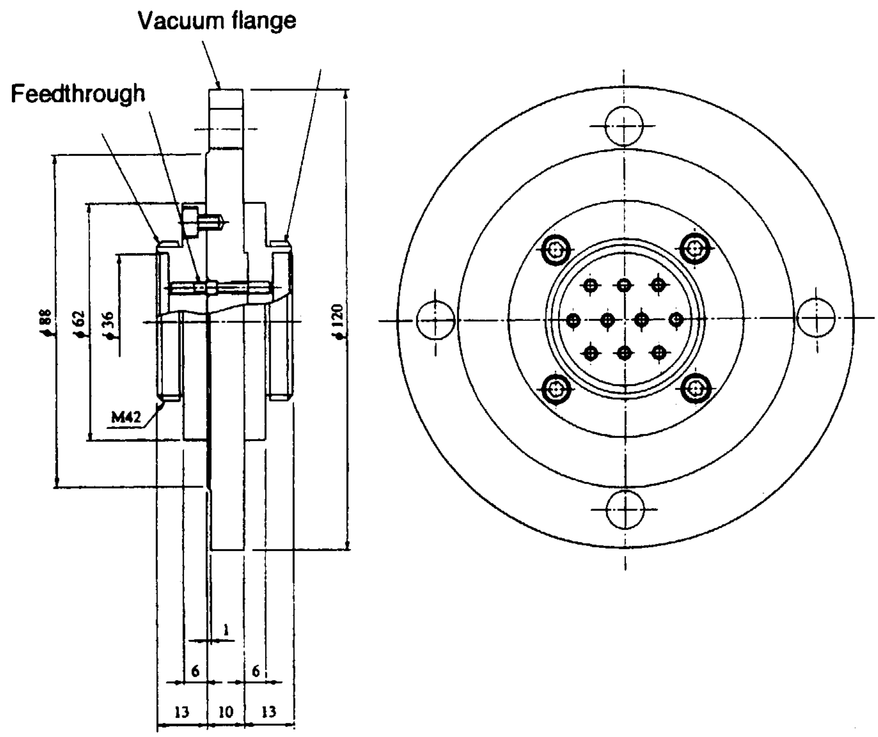


Fig. 4.1-2 Schematic view of the optical-fiber feed through (scale down test-module).

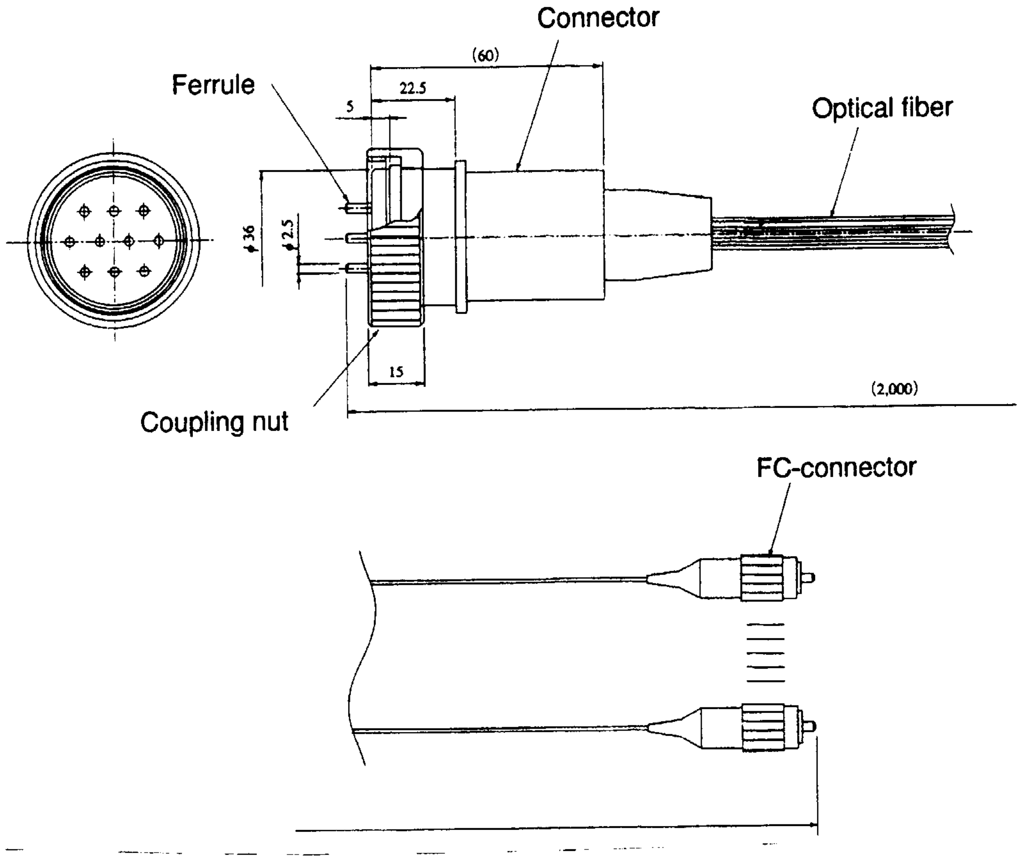


Fig. 4.1-3 Schematic view of the connector (scale down test-module).

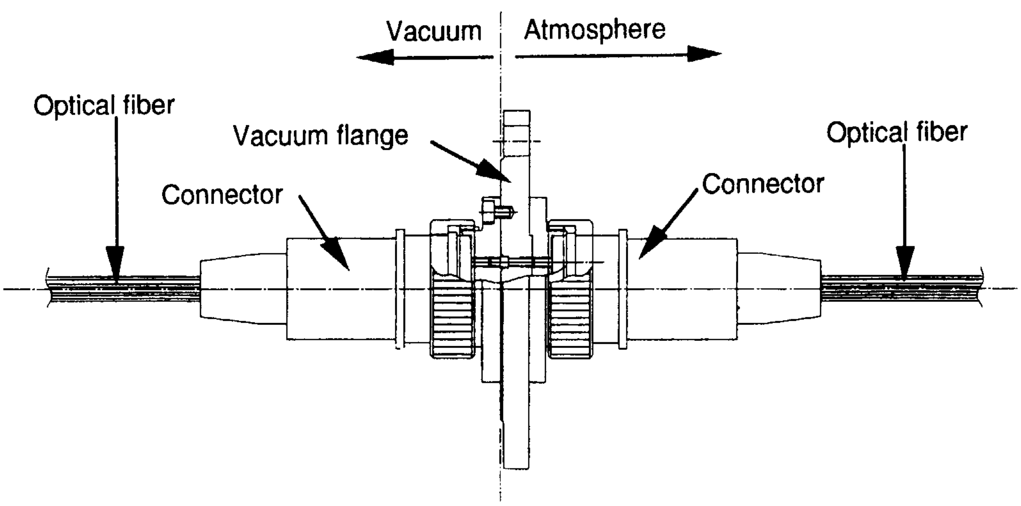


Fig. 4.1-4 Assembly view of the optical-fiber feed through and the connector (scale down test-module).

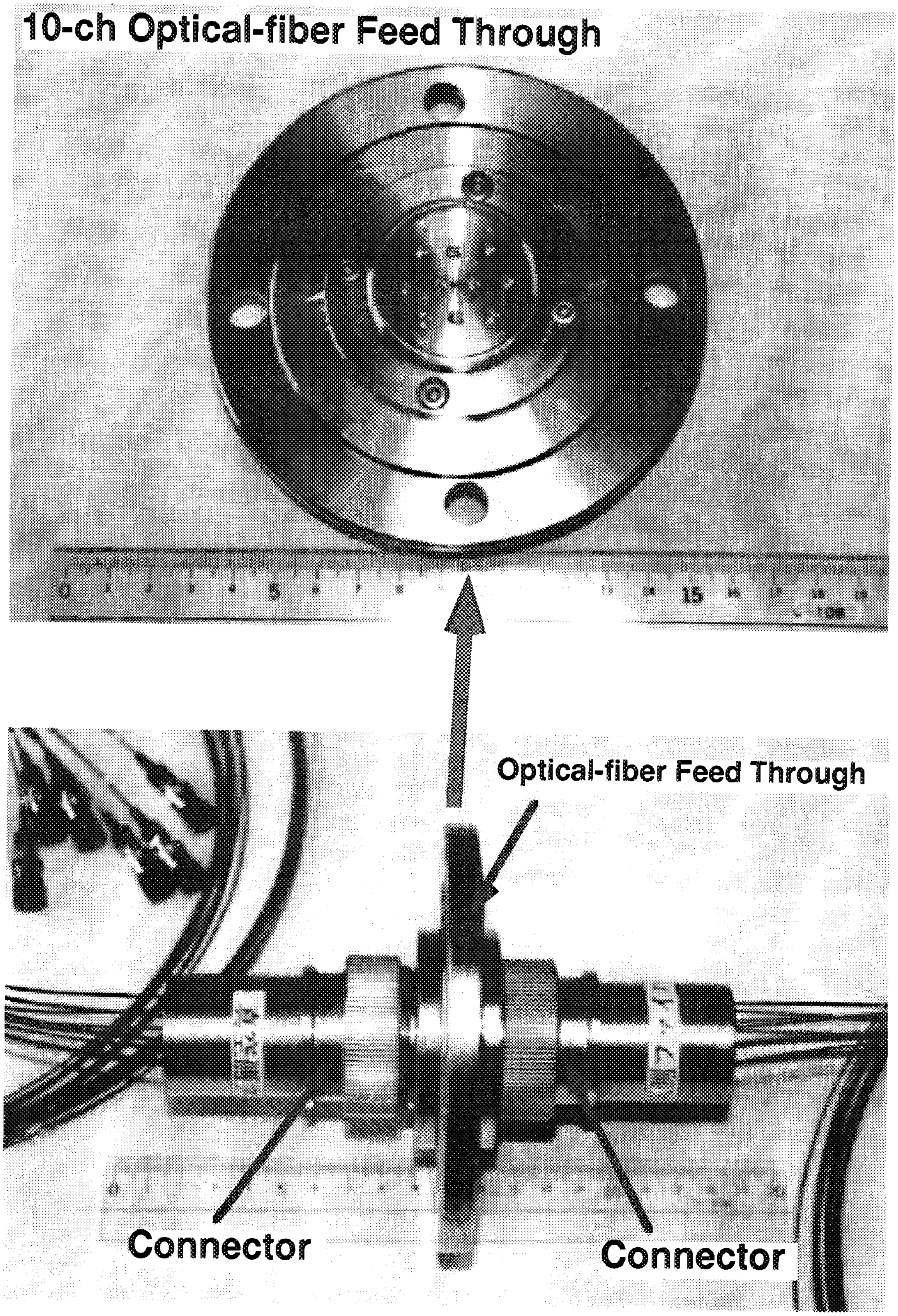


Fig. 4.1-5 Photograph of the optical-fiber feed through (scale down test-module).

4.2 Test and results (Scale down test-module)

The scale down test-module of the optical-fiber feed through and the connectors were manufactured successfully. The vacuum leak test, transmission test, uniformity check, pressurization test, temperature resistance test, acceleration test and reproducibility check were carried out. The requirements were satisfied except for the connecting loss and for the uniformity among each channels. Concerning the connecting loss, the best value was 2.2 dB and the worst one was 13.5 dB as shown in Table 5.1-1(a: before pressure resistance test, temperature resistance test and acceleration test, b: after those tests). This phenomenon was caused by the gap between the fiber center of the connector and that of the feed through. The results comparing with the final requirements are summarized in Table 5.1-2.

The large connecting loss has been solved by improving the fixing method of the optical fiber as described in the next section.

Table 5.1-1(a) Connecting loss before pressure resistance test, temperature resistance test and acceleration test

	Connecting loss (dB)							
Wavelength	350 nm	400 nm	500 nm	600 nm	700 nm	800 nm	900 nm	1000 nm
Channel								
1	2.75	2.76	2.75	2.75	2.76	2.75	2.73	2.76
2	2.88	2.86	2.86	2.87	2.86	2.87	2.85	2.87
3	3.04	3.03	3.03	2.99	3.02	3.02	3.01	3.01
4	2.04	2.05	2.05	2.03	2.04	2.03	2.04	2.04
5	10.46	10.45	10.49	10.48	10.47	10.48	10.49	10.46
6	3.86	3.86	3.89	3.87	3.89	3.87	3.87	3.87
7	4.68	4.65	4.65	4.66	4.68	4.63	4.65	4.67
8	7.6	7.61	7.61	7.64	7.64	7.62	7.61	7.65
9	2.58	2.55	2.56	2.53	2.54	2.56	2.54	2.57
10	2.5	2.54	2.55	2.54	2.51	2.52	2.54	2.54

Table 5.1-1(b) Connecting loss after pressure resistance test, temperature resistance test and acceleration test.

	Connecting loss (dB)							
Wavelength	350 nm	400 nm	500 nm	600 nm	700 nm	800 nm	900 nm	1000 nm
Channel								
1	2.85	2.85	2.86	2.84	2.87	2.86	2.85	2.85
2	2.97	2.97	2.94	2.99	2.98	2.95	2.95	2.97
3	3.18	3.2	3.19	3.18	3.2	3.19	3.18	3.18
4	2.16	2.17	2.16	2.16	2.19	2.17	2.17	2.18
5	13.46	13.45	13.49	13.48	3.47	13.48	13.46	13.49
6	4.05	4.05	4.06	4.05	4.04	4.05	4.03	4.04
7	4.99	5	5.02	4.99	4.97	4.98	4.98	4.96
8	10.34	10.36	10.31	10.33	10.3	10.32	10.3	10.32
9	2.6	2.6	2.59	2.57	2.62	2.6	2.61	2.59
10	2.29	2.28	2.32	2.29	2.31	2.29	2.61	2.28

Table 5.1-2. Summary of result for the scale down test-module comparing with final requirement.

<Item>	< Requiement >	< Result >
Material of fiber core	Fused quartz	Achieved
Diameter of fiber core	200 μm	Achieved
Number of channel	>50	10
Vacuum Seal	He Leak $< 1 \times 10^{-10}$ Pa m^3/s	Achieved
Capacity to Resist Inner Pressure Rise	> 2 atm (second vacuum boundary)	Achieved (5 atm)
Mechanical acceleration of structure	> 15g, duration 10 ms, 1000 cycles	Achieved
Temperature:	20°C - 200°C	Achieved
Temperature ramp rate	> 20°C/hr	Achieved
Uniformity among each channels	> 60 %	Not achieved
Maximum connecting loss per channel	3 dB	2 dB - 14 dB

4.3 Evaluation (Scale down test-module)

The scale down test-module which has ten fiber feed throughs in the vacuum flange was manufactured and tested. The requirements were satisfied except for the connecting loss and for the uniformity among each channels. We evaluated the scale down test-module as follows.

i) The vacuum sealing method described in the section 4.1 is available in the actual feed through.

ii) Concerning the connecting loss, the best value was 2.2 dB and the worst one was 13.5 dB. This phenomenon was caused by the bad accuracy of the gap between the fiber center of the connector and that of the feed through.

It was necessary to improve the design of the part of the feed through in the full performance test-module.

5. Full performance test-module (second phase)

5.1 Design (Full performance test-module)

The full performance test-module has fiber feed throughs of 57 channels on a vacuum flange. The feed through was improved in order to achieve a good transmission and uniformity among the channels by using a fiber rod which diameter of 2.3 mm. The each fiber rod, which is composed of core, clad and jacket, was made by the same method as the optical fiber. The structure is shown in Fig. 5.1-1. The rod is soldered on the vacuum flange by a high temperature solder (sp-27) as shown in Fig. 5.1-2. The schematic views of the part of the optical-fiber feed through, the connector and the partial cross section of the optical-fiber feed through and the connector are shown in Fig. 5.1-2, 3 and 4 respectively. The assembly view and the photographs are also shown in Fig. 5.1-5, 6, 7 and 8.

The accuracy of the gap between the fiber center of the connector and that of the feed through will be improved than that of the scale down test-module, because the soldering position is decreased from two to one for each feed through. .

The specification of the full performance test-module is summarized as follows.

-Material of fiber core :	Fused quartz
-Diameter of fiber core :	200 μm
-Number of channel:	57
-Vacuum Seal Method:	Nickel/Gold plated fiber rod+ high temperature solder (sp-27)
-Capacity to Resist Inner Pressure Rise:	5 atm
-Mechanical acceleration of structure:	> 15g, duration 10 ms, 1000 cycles
-Temperature:	20°C - 200°C
-Uniformity among each channels:	60 % (target)
-Maximum connecting loss per channel:	3 dB (target)
-Connector:	For remote handling

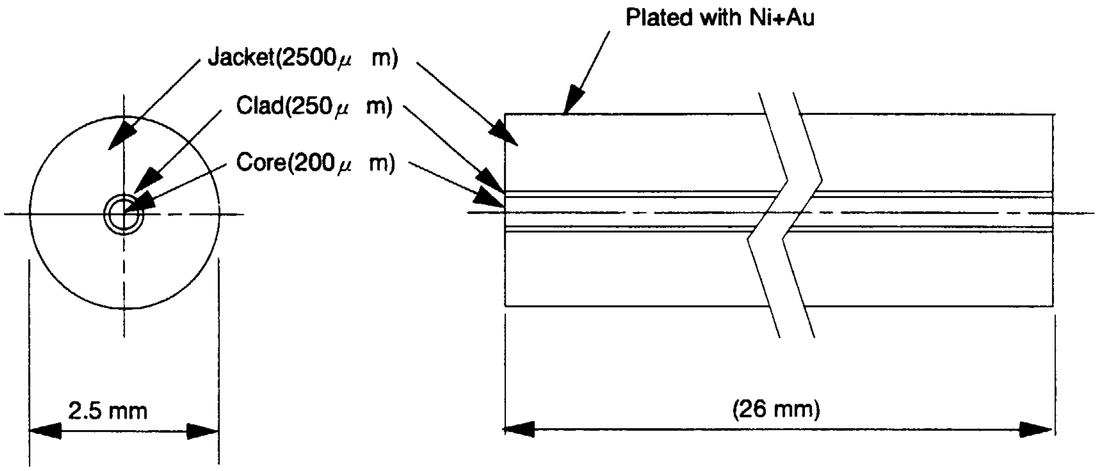


Fig. 5.1-1 Fiber rod. (Core: Fused quartz, Clad: F-dorped fused quartz, Jacket: Fused quartz)
The fiber rod made by the same method as the optical fiber. The rod is plated with Ni and Au.

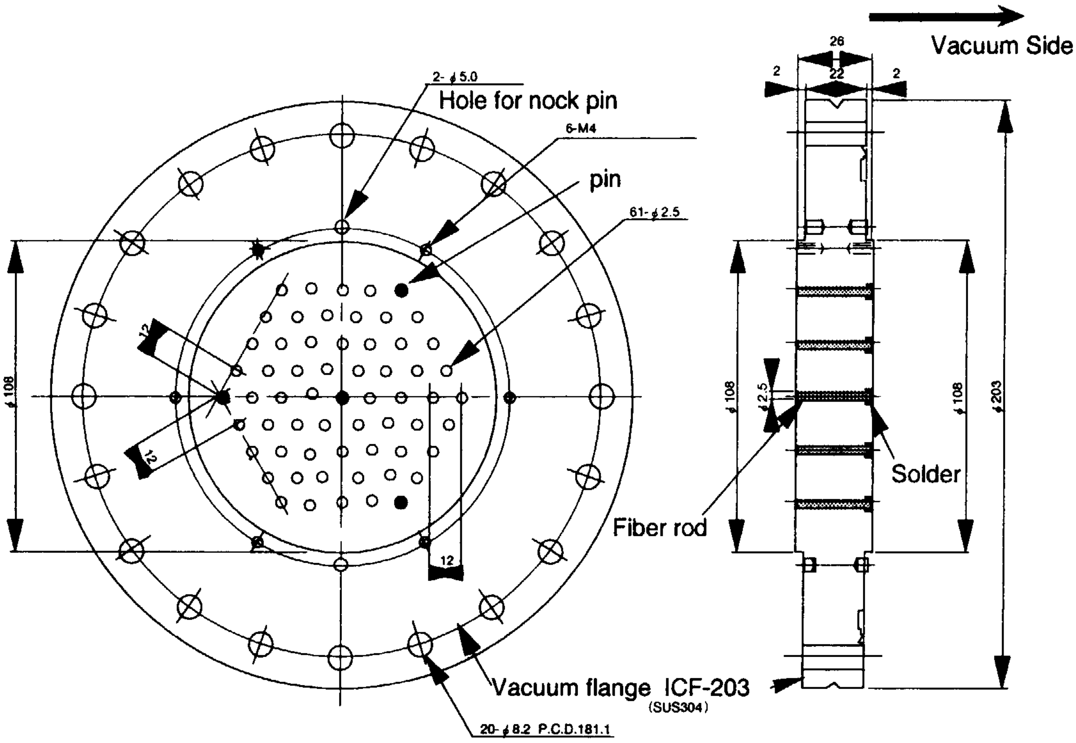


Fig. 5.1-2 Schematic view of the part of the optical-fiber feed through. Tere are 57 fiber feed throughs.

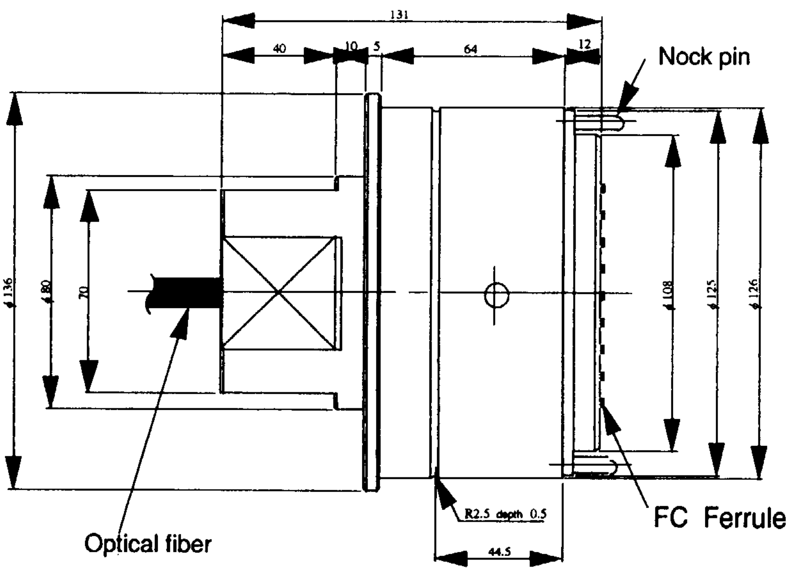


Fig. 5.1-3 Schematic view of connector.

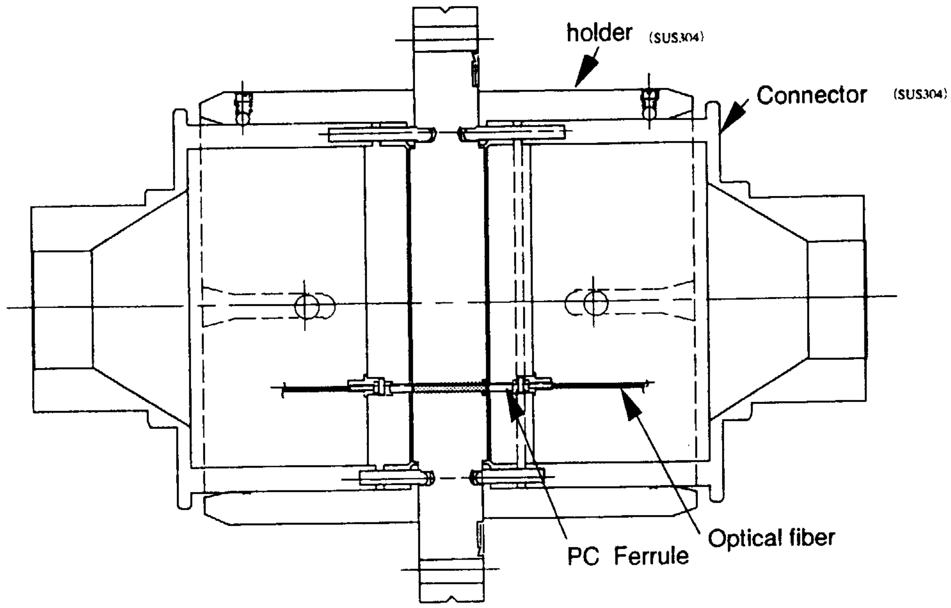


Fig.5.1-4 Partial cross section of the optical-fiber feed through and the connector.

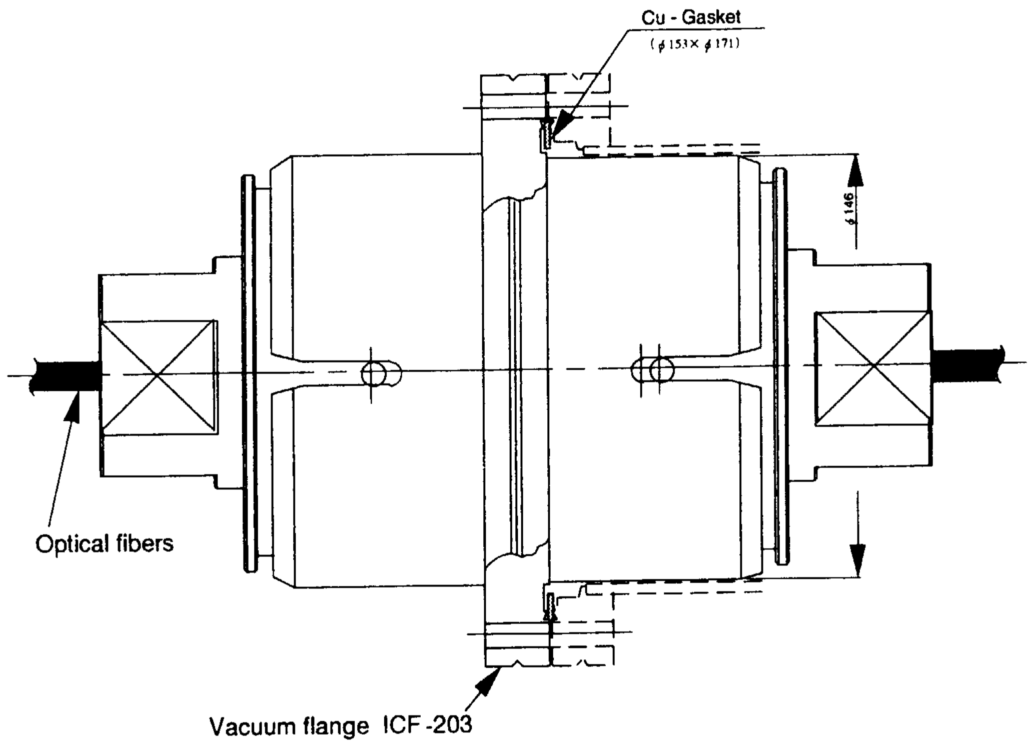


Fig. 5.1-5 Assembly view of the optical fiber feed through.

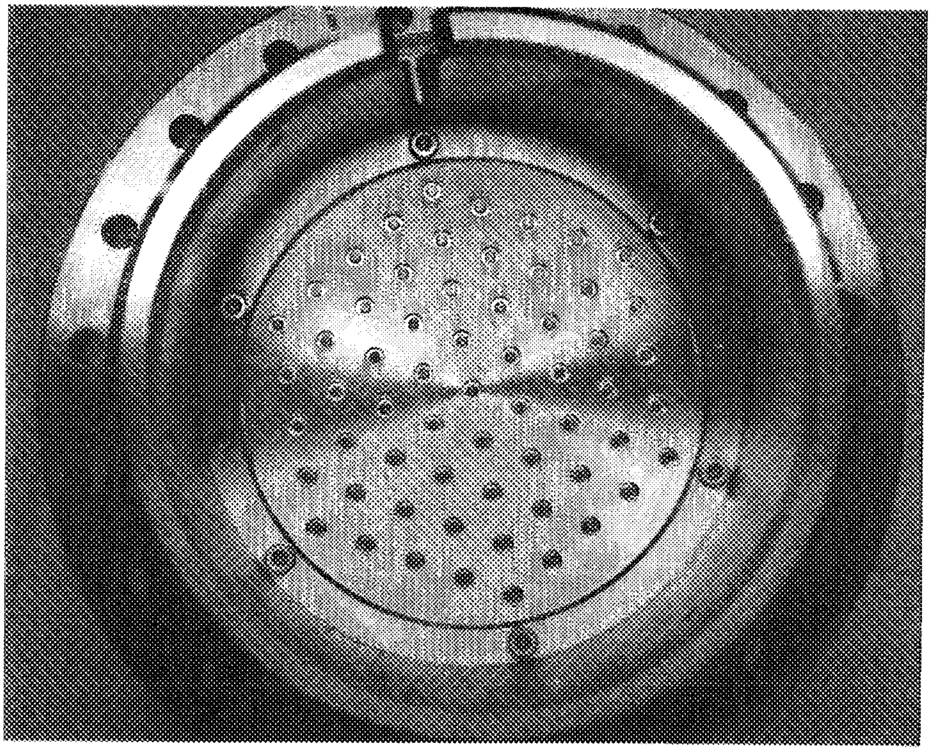


Fig. 5.1-6 Optical-fiber feed through.

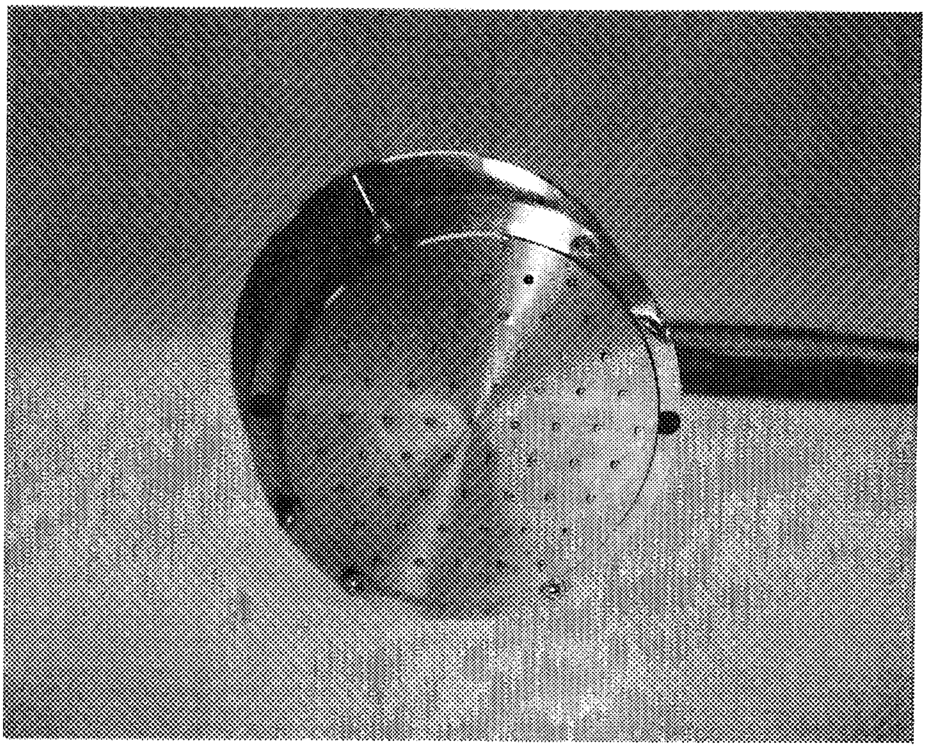


Fig. 5.1-7 Optical connector.

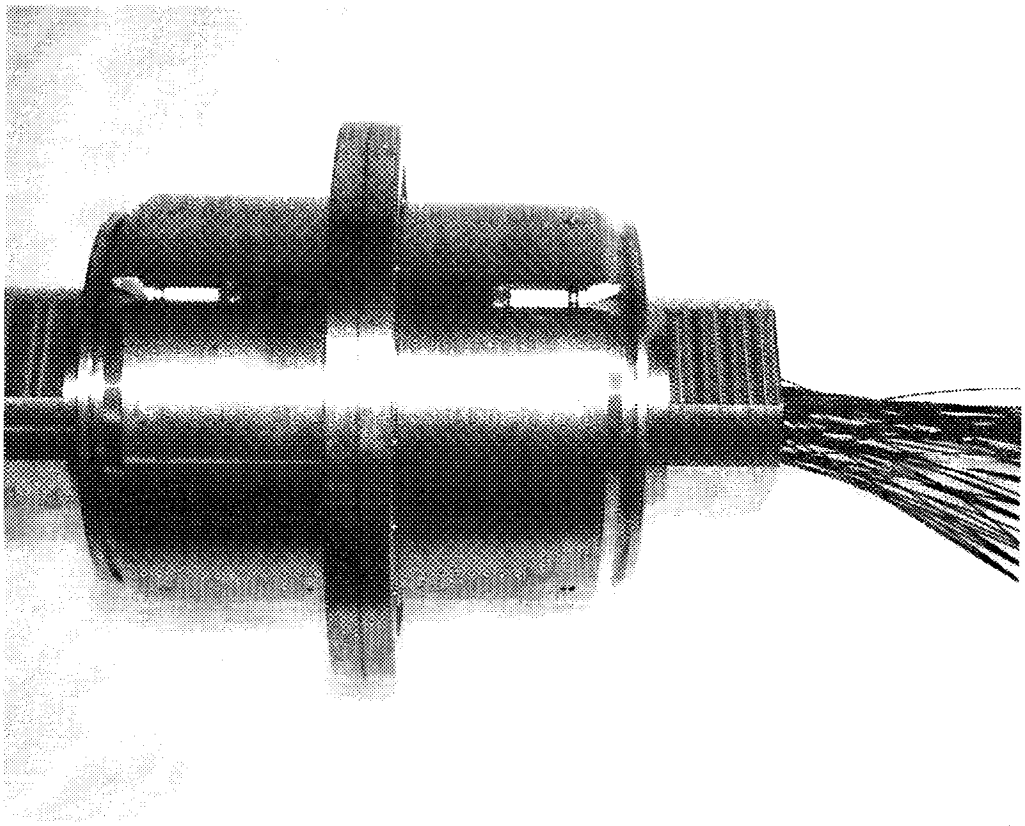


Fig. 5.1-8 Assembled aspect of optical-fiber feed through.

5.2 Test and results (Full performance test-module)

The full performance test-module of the optical-fiber feed through and the connectors were manufactured successfully. The transmission test, the vacuum leak test, the uniformity check, the pressurization test, the temperature resistance test, the acceleration test and the reproducibility check were performed.

The vacuum leak test and the transmission test were carried out befor and after the temperature resistance test, the pressurization test and the acceleration test.

The details are described following sections. The requirements of the work order were almost satisfied.

5.2.1 Transmission test

The connecting losses were measured with an optical spectrum analyzer at wavelengths of 350 nm, 400 nm, 500 nm, 600 nm, 700 nm, 800 nm, 900 nm and 1000 nm as shown in Fig. 5.2-1. The connecting loss L_c is written as

$$L_c = -10 \times \log (P_n/P_R) \qquad (5.2\text{-}1),$$

where P_n is the transmitted power of the channel n (see Fig.5.2-2) and P_R is the transmitted power of the reference fiber.

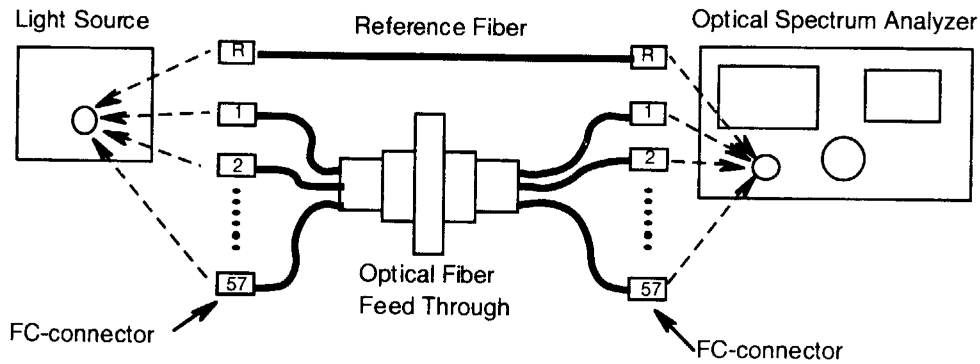


Fig. 5.2-1 Measuring arrangement of connecting loss.

The measurements were carried out before and after the temperature resistance test, the pressurization test and the acceleration test. Those results of before and after those tests are shown in Table 5.2-1 and in Table 5.2-2 respectively. These results shows that the required maximum connecting loss of 3 dB was satisfied before and after the tests by omitting the shadowed channels as shown in those tables. 53 channels of the feed through satisfied the requirement.

The required uniformity of > 60 % was also satisfied as shown in those tables. Here, the uniformity U is defined as

$$U = T_{min} / T_{max} \qquad (5.2\text{-}2),$$

where T_{min} is the minimum value and T_{max} is the maximum value of transmissivity among each channels.

The measurement of the transmissivity was carried out after the put on and take off test. The difference of transmissivity

ΔT = T(after put on and take off test) - T(before put on and take off test)

is shown in Table 5.2-3. The maximum difference was 15.4 % and the averaged value was 2.8 %.

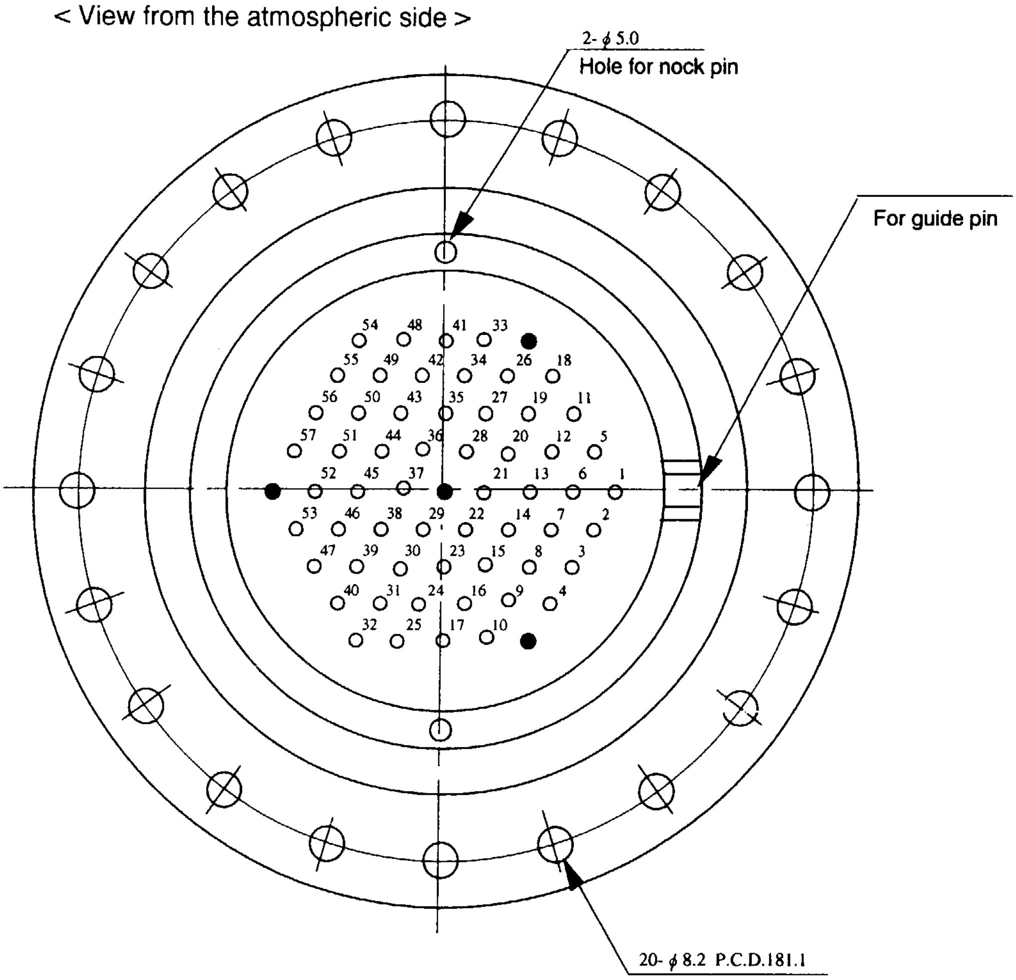


Fig. 5.2-2 Channel number of the feed through.

Table 5.2-1 Connecting loss and transmissivity of each channel before tests. Shadowed channels were omitted.
53 channels of feed through are available.

ch	350 nm		400 nm		500 nm		600 nm		700 nm		800 nm		900 nm		1000 nm	
	Loss(dB)	T	Loss(dB)	T	Loss(dB)	T	Loss(dB)	T	Loss(dB)	T	Loss(dB)	T	Loss(dB)	T	Loss(dB)	T
1	1.36	73.1%	1.83	65.6%	1.67	68.1%	1.60	69.2%	1.57	69.7%	1.52	70.5%	1.43	71.9%	1.49	71.0%
2	2.47	56.6%	2.49	56.4%	2.76	53.0%	2.50	56.2%	2.52	56.0%	2.36	58.1%	2.33	58.5%	2.34	58.3%
3	1.10	77.6%	1.31	74.0%	1.28	74.5%	1.32	73.8%	1.31	74.0%	1.18	76.2%	1.21	75.7%	1.16	76.6%
4	2.49	56.4%	2.61	54.8%	2.74	53.2%	2.76	53.0%	2.38	57.8%	2.30	58.9%	2.30	58.9%	2.27	59.3%
5	**2.96**	**50.6%**	**2.91**	**51.2%**	**3.23**	**47.5%**	**3.25**	**47.3%**	**2.82**	**52.2%**	**2.69**	**53.8%**	**2.65**	**54.3%**	**2.66**	**54.2%**
6	1.18	76.2%	1.59	69.3%	1.51	70.6%	1.56	69.8%	1.58	69.5%	1.33	73.6%	1.29	74.3%	1.30	74.1%
7	1.60	69.2%	1.95	63.8%	1.94	64.0%	1.81	65.9%	1.83	65.6%	1.75	66.8%	1.67	68.1%	1.71	67.5%
8	1.04	75.0%	1.04	78.7%	0.96	80.2%	0.92	80.9%	0.96	80.2%	0.80	83.2%	0.76	83.9%	0.76	83.9%
9	1.12	77.3%	1.56	69.8%	1.48	71.1%	1.42	72.1%	1.37	72.9%	1.29	74.3%	1.16	76.6%	1.24	75.2%
10	0.48	89.5%	0.75	84.1%	0.71	84.9%	0.82	82.8%	0.80	83.2%	0.68	85.5%	0.54	88.3%	0.63	86.5%
11	2.56	55.5%	2.29	59.0%	2.68	54.0%	2.16	60.8%	2.35	58.2%	2.13	61.2%	2.26	59.4%	2.13	61.2%
12	1.36	73.1%	1.51	70.6%	1.51	70.6%	1.44	71.8%	1.47	71.3%	1.30	74.1%	1.45	71.6%	1.30	74.1%
13	0.72	84.7%	0.95	80.4%	0.82	82.8%	0.84	82.4%	0.85	82.2%	0.72	84.7%	0.76	83.9%	0.72	84.7%
14	2.33	58.5%	2.29	59.0%	2.56	55.5%	2.06	62.2%	2.06	62.2%	1.99	63.2%	1.97	63.5%	1.92	64.3%
15	1.56	69.8%	1.84	65.5%	1.76	66.7%	1.62	68.9%	1.62	68.9%	1.59	69.3%	1.73	67.1%	1.59	69.3%
16	1.34	73.5%	1.55	70.0%	1.55	70.0%	1.48	71.1%	1.52	70.5%	1.33	73.6%	1.42	72.1%	1.28	74.5%
17	1.11	77.4%	1.34	73.5%	1.23	75.3%	1.16	76.6%	1.21	75.7%	1.15	76.7%	1.19	76.0%	1.23	75.3%
18	1.06	78.3%	1.27	74.6%	1.17	76.4%	1.06	78.3%	1.11	77.4%	1.00	79.4%	1.07	78.2%	1.00	79.4%
19	1.62	68.9%	1.83	65.6%	1.93	64.1%	1.73	67.1%	1.76	66.7%	1.71	67.5%	1.66	68.2%	1.77	66.5%
20	1.07	78.2%	1.20	75.9%	1.16	76.6%	1.16	76.6%	1.24	75.2%	1.09	77.8%	1.09	77.8%	1.06	78.3%
21	2.23	59.8%	2.11	61.5%	2.37	57.9%	1.93	64.1%	1.94	64.0%	1.76	66.7%	1.95	63.8%	1.86	65.2%
22	1.11	77.4%	1.28	74.5%	1.22	75.5%	1.21	75.7%	1.16	76.6%	1.04	78.7%	1.15	76.7%	1.09	77.8%
23	1.44	71.8%	1.61	69.0%	1.59	69.3%	1.54	70.1%	1.46	71.4%	1.43	71.9%	1.41	72.3%	1.33	73.6%
24	2.58	55.2%	2.33	58.5%	2.72	53.5%	2.25	59.6%	2.31	58.7%	2.10	61.7%	2.33	58.5%	2.21	60.1%
25	1.56	69.8%	1.97	63.5%	1.87	65.0%	1.78	66.4%	1.76	66.7%	1.62	68.9%	1.69	67.8%	1.67	68.1%
26	1.78	66.4%	1.97	63.5%	2.32	58.6%	1.94	64.0%	1.86	65.2%	1.78	66.4%	1.82	65.8%	1.84	65.5%
27	2.48	56.5%	2.68	54.0%	2.79	52.6%	2.78	52.7%	2.41	57.4%	2.25	59.6%	2.53	55.8%	2.62	54.7%
28	1.83	65.6%	2.25	59.6%	2.47	56.6%	1.97	63.5%	1.90	64.6%	1.80	66.1%	1.95	63.8%	1.86	65.2%
29	1.69	67.8%	2.05	62.4%	2.29	59.0%	1.85	65.3%	1.82	65.8%	1.68	67.9%	1.79	66.2%	1.76	66.7%
30	1.73	67.1%	2.00	63.1%	2.31	58.7%	1.93	64.1%	1.90	64.6%	1.73	67.1%	1.79	66.2%	1.81	65.9%
31	1.50	70.8%	1.78	66.4%	1.75	66.8%	1.56	69.8%	1.57	69.7%	1.51	70.6%	1.59	69.3%	1.49	71.0%
32	1.34	73.5%	1.59	69.3%	1.58	69.5%	1.35	73.3%	1.38	72.8%	1.31	74.0%	1.33	73.6%	1.37	72.9%
33	1.26	74.8%	1.39	72.6%	1.42	72.1%	1.30	74.1%	1.28	74.5%	1.28	74.5%	1.24	75.2%	1.23	75.3%
34	1.52	70.5%	1.83	65.6%	1.75	66.8%	1.62	68.9%	1.59	69.3%	1.47	71.3%	1.6	69.2%	1.48	71.1%
35	2.46	56.8%	2.09	61.8%	2.51	56.1%	2.04	62.5%	2.04	62.5%	1.91	64.4%	2.06	62.2%	1.93	64.1%
36	1.76	66.7%	1.87	65.0%	2.3	58.9%	1.78	66.4%	1.83	65.6%	1.69	67.8%	1.84	65.5%	1.7	67.6%
37	1.39	72.6%	1.67	68.1%	1.63	68.7%	1.44	71.8%	1.49	71.0%	1.34	73.5%	1.49	71.0%	1.36	73.1%
38	2.52	56.0%	2.42	57.3%	2.74	53.2%	1.92	64.3%	2.21	60.1%	1.85	65.3%	1.89	64.7%	1.93	64.1%
39	1.83	65.6%	2.11	61.5%	2.51	56.1%	1.96	63.7%	1.98	63.4%	1.84	65.5%	1.81	65.9%	1.78	66.4%
40	1.09	77.8%	1.53	70.3%	1.5	70.8%	1.26	74.8%	1.19	76.0%	1.14	76.9%	1.14	76.9%	1.1	77.6%
41	1.73	67.1%	1.84	65.5%	1.81	65.9%	1.71	67.5%	1.73	67.1%	1.76	66.7%	1.74	67.0%	1.73	67.1%
42	**3.15**	**48.4%**	**2.96**	**50.6%**	**3.27**	**47.1%**	**3.22**	**47.6%**	**3.2**	**47.9%**	**2.79**	**52.6%**	**2.71**	**53.6%**	**2.75**	**53.1%**
43	**3.35**	**46.2%**	**3.5**	**44.7%**	**3.7**	**42.7%**	**3.54**	**44.3%**	**3.16**	**48.3%**	**2.67**	**54.1%**	**2.79**	**52.6%**	**2.88**	**51.5%**
44	1.61	69.0%	1.85	65.3%	1.78	66.4%	1.8	66.1%	1.76	66.7%	1.7	67.6%	1.66	68.2%	1.71	67.5%
45	2.37	57.9%	2.23	59.8%	2.58	55.2%	2.14	61.1%	2.04	62.5%	2.04	62.5%	1.99	63.2%	2.03	62.7%
46	1.06	78.3%	1.29	74.3%	1.24	75.2%	1.32	73.8%	1.09	77.8%	1.08	78.0%	1.09	77.8%	1.08	78.0%
47	1.81	65.9%	1.97	63.5%	2.32	58.6%	1.93	64.1%	1.74	67.0%	1.76	66.7%	1.92	64.3%	1.77	66.5%
48	1.81	65.9%	2.27	59.3%	2.54	55.7%	2.15	61.0%	1.87	65.0%	1.86	65.2%	1.92	64.3%	1.87	65.0%
49	1.81	65.9%	1.95	63.8%	2.34	58.3%	1.93	64.1%	1.77	66.5%	1.77	66.5%	1.81	65.9%	1.76	66.7%
50	1.74	67.0%	2.08	61.9%	2.42	57.3%	1.98	63.4%	1.91	64.4%	1.89	64.7%	1.72	67.3%	1.84	65.5%
51	1.16	76.6%	1.47	71.3%	1.32	73.8%	1.27	74.6%	1.17	76.4%	1.17	76.4%	1.13	77.1%	1.17	76.4%
52	1.54	70.1%	1.81	65.9%	1.72	67.3%	1.65	68.4%	1.54	70.1%	1.55	70.0%	1.59	69.3%	1.53	70.3%
53	1.23	75.3%	1.53	70.3%	1.4	72.4%	1.35	73.3%	1.35	73.3%	1.24	75.2%	1.34	73.5%	1.2	75.9%
54	1.11	77.4%	1.46	71.4%	1.32	73.8%	1.31	74.0%	1.25	75.0%	1.17	76.4%	1.25	75.0%	1.12	77.3%
55	**2.97**	**50.5%**	**3.08**	**49.2%**	**3.29**	**46.9%**	**3.15**	**48.4%**	**3.1**	**49.0%**	**2.5**	**56.2%**	**2.79**	**52.6%**	**2.68**	**54.0%**
56	2	63.1%	2.16	60.8%	2.41	57.4%	2.38	57.8%	2.24	59.7%	1.9	64.6%	1.94	64.0%	1.2	75.9%
57	0.99	79.6%	1.2	75.9%	1.13	77.1%	1.01	79.3%	1	79.4%	1.03	78.9%	0.95	80.4%	0.96	80.2%

	350 nm	400 nm	500 nm	600 nm	700 nm	800 nm	900 nm	1000 nm
$T_{min.}$	55.2%	54.0%	52.6%	52.7%	56.0%	58.1%	55.8%	54.7%
$T_{max.}$	89.5%	84.1%	84.9%	82.8%	83.2%	85.5%	88.3%	86.5%

Uniformoty $\equiv T_{min}/T_{max.}$

350 nm	400 nm	500 nm	600 nm	700 nm	800 nm	900 nm	1000 nm
61.7%	64.1%	61.9%	63.7%	67.3%	67.9%	63.2%	63.2%

Table 5.2-2 Connecting loss and transmissivity T of each channel after temperature resistance test, pressurization test and acceleration test. Shadowed channels were omitted. 53 channels of feed through are available.

	350 nm		400 nm		500 nm		600 nm		700 nm		800 nm		900 nm		1000 nm	
ch	Loss(dB)	T	Loss(dB)	T	Loss(dB)	T	Loss(dB)	T	Loss(dB)	T	Loss(dB)	T	Loss(dB)	T	Loss(dB)	T
1	1.52	70.5%	1.68	67.9%	1.6	69.2%	1.78	66.4%	1.73	67.1%	1.61	69.0%	1.53	70.3%	1.69	67.8%
2	2.53	55.8%	2.56	55.5%	2.81	52.4%	2.51	56.1%	2.54	55.7%	2.16	60.8%	2.21	60.1%	2.3	58.9%
3	1.41	72.3%	1.51	70.6%	1.58	69.5%	1.6	69.2%	1.61	69.0%	1.48	71.1%	1.5	70.8%	1.32	73.8%
4	1.52	70.5%	1.65	68.4%	1.61	69.0%	1.75	66.8%	1.69	67.8%	1.55	70.0%	1.55	70.0%	1.65	68.4%
5	**2.91**	**51.2%**	**2.95**	**50.7%**	**3.1**	**49.0%**	**3.24**	**47.4%**	**2.97**	**50.5%**	**2.74**	**53.2%**	**2.71**	**53.6%**	**2.71**	**53.6%**
6	1.04	78.7%	1.46	71.4%	1.41	72.3%	1.42	72.1%	1.44	71.8%	1.36	73.1%	1.33	73.6%	1.3	74.1%
7	1.71	67.5%	2.01	63.0%	2.02	62.8%	1.95	63.8%	1.85	65.3%	1.84	65.5%	1.78	66.4%	1.75	66.8%
8	1.15	75.0%	1.14	76.9%	1.08	78.0%	1.01	79.3%	1.03	78.9%	0.95	80.4%	0.96	80.2%	0.91	81.1%
9	1.32	73.8%	1.63	68.7%	1.58	69.5%	1.54	70.1%	1.49	71.0%	1.41	72.3%	1.32	73.8%	1.36	73.1%
10	0.5	89.1%	0.73	84.5%	0.73	84.5%	0.85	82.2%	0.86	82.0%	0.72	84.7%	0.6	87.1%	0.62	86.7%
11	1.59	69.3%	1.6	69.2%	1.61	69.0%	1.67	68.1%	1.55	70.0%	1.39	72.6%	1.54	70.1%	1.5	70.8%
12	1.37	72.9%	1.42	72.1%	1.46	71.4%	1.51	70.6%	1.52	70.5%	1.4	72.4%	1.46	71.4%	1.36	73.1%
13	0.76	83.9%	0.95	80.4%	0.88	81.7%	0.84	82.4%	0.9	81.3%	0.81	83.0%	0.79	83.4%	0.78	83.6%
14	1.97	63.5%	1.92	64.3%	2.1	61.7%	1.88	64.9%	1.85	65.3%	1.79	66.2%	1.78	66.4%	1.76	66.7%
15	1.49	71.0%	1.74	67.0%	1.72	67.3%	1.58	69.5%	2.13	61.2%	1.45	71.6%	1.62	68.9%	1.47	71.3%
16	1.44	71.8%	1.61	69.0%	1.59	69.3%	1.56	69.8%	1.46	71.4%	1.44	71.8%	1.43	71.9%	1.37	72.9%
17	1.12	77.3%	1.34	73.5%	1.31	74.0%	1.27	74.6%	1.21	75.7%	1.08	78.0%	1.24	75.2%	1.1	77.6%
18	1.09	77.8%	1.29	74.3%	1.28	74.5%	1.18	76.2%	1.17	76.4%	1.26	74.8%	1.09	77.8%	1.16	76.6%
19	1.68	67.9%	1.96	63.7%	2.28	59.2%	1.87	65.0%	1.88	64.9%	1.74	67.0%	1.8	66.1%	1.66	68.2%
20	1.1	77.6%	1.2	75.9%	1.16	76.6%	1.16	76.6%	1.24	75.2%	1.09	77.8%	1.09	77.8%	1.12	77.3%
21	1.63	68.7%	1.58	69.5%	1.57	69.7%	1.55	70.0%	1.55	70.0%	1.42	72.1%	1.5	70.8%	1.5	70.8%
22	1.14	76.9%	1.25	75.0%	1.21	75.7%	1.16	76.6%	1.55	70.0%	1.42	72.1%	1.5	70.8%	1.5	70.8%
23	1.66	68.2%	1.9	64.6%	1.77	66.5%	1.79	66.2%	1.71	67.5%	1.83	65.6%	1.59	69.3%	1.69	67.8%
24	2.08	61.9%	2.31	58.7%	2.61	54.8%	2.2	60.3%	2.28	59.2%	2.08	61.9%	2.13	61.2%	2.11	61.5%
25	1.48	71.1%	1.56	69.8%	1.62	68.9%	1.63	68.7%	1.54	70.1%	1.49	71.0%	1.55	70.0%	1.51	70.6%
26	2.01	63.0%	2.42	57.3%	2.49	56.4%	2.29	59.0%	2.21	60.1%	2.21	60.1%	2.19	60.4%	2.01	63.0%
27	2.35	58.2%	2.47	56.6%	2.59	55.1%	2.53	55.8%	2.54	55.7%	2.31	58.7%	2.51	56.1%	2.41	57.4%
28	1.68	67.9%	1.88	64.9%	2.41	57.4%	2.11	61.5%	1.95	63.8%	1.87	65.0%	1.82	65.8%	1.94	64.0%
29	1.58	69.5%	1.82	65.8%	1.79	66.2%	1.76	66.7%	1.68	67.9%	1.6	69.2%	1.59	69.3%	1.65	68.4%
30	1.83	65.6%	2.32	58.6%	2.56	55.5%	2.38	57.8%	2.12	61.4%	2.18	60.5%	2.19	60.4%	1.92	64.3%
31	1.14	76.9%	1.23	75.3%	1.22	75.5%	1.21	75.7%	1.15	76.7%	1.13	77.1%	1.1	77.6%	1.11	77.4%
32	1.39	72.6%	1.65	68.4%	1.58	69.5%	1.49	71.0%	1.43	71.9%	1.4	72.4%	1.36	73.1%	1.27	74.6%
33	1.18	76.2%	1.35	73.3%	1.26	74.8%	1.3	74.1%	1.18	76.2%	1.23	75.3%	1.09	77.8%	1.18	76.2%
34	1.39	72.6%	1.73	67.1%	1.7	67.6%	1.68	67.9%	1.66	68.2%	1.46	71.4%	1.57	69.7%	1.44	71.8%
35	1.85	65.3%	2.03	62.7%	2.61	54.8%	2.07	62.1%	2.09	61.8%	2.01	63.0%	1.95	63.8%	2	63.1%
36	1.73	67.1%	1.96	63.7%	2.33	58.5%	1.96	63.7%	1.83	65.6%	1.74	67.0%	1.75	66.8%	1.8	66.1%
37	1.42	72.1%	1.85	65.3%	1.69	67.8%	1.62	68.9%	1.53	70.3%	1.61	69.0%	1.41	72.3%	1.58	69.5%
38	1.73	67.1%	1.9	64.6%	1.84	65.5%	1.85	65.3%	1.92	64.3%	1.62	68.9%	1.79	66.2%	1.71	67.5%
39	1.52	70.5%	1.76	66.7%	1.77	66.5%	1.61	69.0%	2.18	60.5%	1.46	71.4%	1.64	68.5%	1.51	70.6%
40	1.21	75.7%	1.65	68.4%	1.58	69.5%	1.46	71.4%	1.42	72.1%	1.43	71.9%	1.45	71.6%	1.37	72.9%
41	1.39	72.6%	1.73	67.1%	1.5	70.8%	1.49	71.0%	1.53	70.3%	1.52	70.5%	1.36	73.1%	1.45	71.6%
42	**3.21**	**47.8%**	**3.01**	**50.0%**	**3.28**	**47.0%**	**3.25**	**47.3%**	**3.16**	**48.3%**	**2.81**	**52.4%**	**2.74**	**53.2%**	**2.71**	**53.6%**
43	**3.24**	**47.4%**	**3.31**	**46.7%**	**3.52**	**44.5%**	**3.48**	**44.9%**	**3.06**	**49.4%**	**2.71**	**53.6%**	**2.81**	**52.4%**	**2.78**	**52.7%**
44	1.48	71.1%	1.87	65.0%	1.68	67.9%	1.71	67.5%	1.65	68.4%	1.42	72.1%	1.65	68.4%	1.45	71.6%
45	2.41	57.4%	2.51	56.1%	2.62	54.7%	2.63	54.6%	2.64	54.5%	2.41	57.4%	2.34	58.3%	2.21	60.1%
46	1.1	77.6%	1.28	74.5%	1.41	72.3%	1.26	74.8%	1.3	74.1%	1.14	76.9%	1.34	73.5%	1.2	75.9%
47	1.82	65.8%	1.94	64.0%	2.35	58.2%	1.98	63.4%	1.89	64.7%	1.93	64.1%	1.81	65.9%	1.82	65.8%
48	1.56	69.8%	2.06	62.2%	1.94	64.0%	1.81	65.9%	1.72	67.3%	1.69	67.8%	1.68	67.9%	1.71	67.5%
49	1.7	67.6%	1.89	64.7%	2.22	60.0%	1.86	65.2%	1.74	67.0%	1.61	69.0%	1.76	66.7%	1.72	67.3%
50	1.81	65.9%	2.02	62.8%	2.35	58.2%	2	63.1%	1.94	64.0%	1.68	67.9%	1.85	65.3%	1.8	66.1%
51	1.85	65.3%	2.01	63.0%	2.4	57.5%	2.01	63.0%	2.02	62.8%	1.72	67.3%	1.88	64.9%	1.82	65.8%
52	1.57	69.7%	1.69	67.8%	1.67	68.1%	1.76	66.7%	1.64	68.5%	1.41	72.3%	1.64	68.5%	1.53	70.3%
53	1.18	76.2%	1.41	72.3%	1.43	71.9%	1.32	73.8%	1.36	73.1%	1.27	74.6%	1.52	70.5%	1.21	75.7%
54	0.98	79.8%	1.51	70.6%	1.41	72.3%	1.46	71.4%	1.45	71.6%	1.34	73.5%	1.42	72.1%	1.42	72.1%
55	**2.96**	**50.6%**	**3.01**	**50.0%**	**3.3**	**46.8%**	**3.18**	**48.1%**	**3.16**	**48.3%**	**2.52**	**56.0%**	**2.82**	**52.2%**	**2.73**	**53.3%**
56	2.38	57.8%	2.48	56.5%	2.53	55.8%	2.51	56.1%	2.34	58.3%	2.43	57.1%	2.34	58.3%	2.41	57.4%
57	0.71	84.9%	1.32	73.8%	1.26	74.8%	1.21	75.7%	1.14	76.9%	1.19	76.0%	1.14	76.9%	1.22	75.5%

	350 nm	400 nm	500 nm	600 nm	700 nm	800 nm	900 nm	1000 nm
$T_{min.}$	55.8%	55.5%	52.4%	54.6%	54.5%	57.1%	56.1%	57.4%
$T_{max.}$	89.1%	84.5%	84.5%	82.4%	82.0%	84.7%	87.1%	86.7%

Uniformoty $\equiv T_{min}/T_{max.}$

62.7%	65.6%	61.9%	66.2%	66.4%	67.5%	64.4%	66.2%

Table 5.2-3 The difference of transmissivity between after and before put on and take off test of the connector.
ΔT = T(after put on and take off test) - T(before put on and take off test)

ch	350 nm ΔT	400 nm ΔT	500 nm ΔT	600 nm ΔT	700 nm ΔT	800 nm ΔT	900 nm ΔT	1000 nm ΔT
1	1.6%	0.5%	-0.2%	3.0%	3.0%	1.9%	2.0%	3.7%
2	-0.6%	-0.8%	1.2%	-0.9%	-0.9%	-3.4%	-2.4%	-1.1%
3	0.5%	-2.2%	1.5%	0.2%	2.4%	1.5%	2.7%	-0.3%
4	-1.4%	-2.0%	-2.3%	-0.9%	-0.5%	-3.3%	-0.5%	0.5%
5	**0.4%**	**3.4%**	**0.7%**	**-0.7%**	**-1.7%**	**-2.9%**	**-0.2%**	**-0.1%**
6	-0.9%	1.5%	0.0%	2.4%	2.2%	3.8%	-0.8%	3.1%
7	1.1%	3.7%	-1.4%	1.2%	0.5%	2.1%	1.5%	0.0%
8	0.3%	-4.8%	-4.2%	-7.0%	-5.1%	-6.6%	-5.2%	-5.9%
9	4.0%	3.4%	4.1%	4.8%	5.8%	3.9%	4.0%	3.3%
10	-1.8%	-2.7%	-0.4%	1.7%	3.5%	0.2%	0.8%	-1.2%
11	-13.8%	-10.2%	**-15.4%**	-10.7%	-11.8%	-13.5%	-10.4%	-12.9%
12	2.2%	1.0%	1.7%	1.5%	3.8%	2.0%	3.9%	-0.3%
13	-1.0%	0.4%	-0.9%	-1.9%	-0.4%	-0.2%	-2.1%	-1.7%
14	4.1%	-0.3%	4.3%	0.3%	1.5%	-0.6%	1.7%	0.3%
15	-4.3%	-2.0%	-2.0%	-2.5%	5.4%	-5.4%	-2.2%	-4.5%
16	-2.8%	-3.7%	-4.9%	-4.1%	-5.7%	-5.1%	-3.7%	-6.3%
17	-0.7%	-1.5%	-1.0%	-0.9%	-3.4%	-2.8%	2.6%	-4.2%
18	1.4%	1.7%	1.0%	1.1%	0.9%	1.9%	1.6%	-0.4%
19	2.1%	-0.9%	-2.7%	-3.2%	-1.5%	-2.0%	-1.2%	-3.7%
20	-1.9%	-4.6%	-4.9%	-3.8%	-0.3%	-3.8%	-0.5%	-1.6%
21	**11.8%**	7.4%	6.9%	6.8%	7.3%	5.7%	7.2%	4.9%
22	1.6%	-0.2%	0.0%	-0.4%	7.3%	5.9%	4.9%	4.5%
23	2.2%	0.7%	-1.7%	0.0%	0.5%	3.1%	-0.5%	0.6%
24	-1.8%	-1.6%	1.4%	-3.5%	-0.9%	-3.5%	-2.8%	-3.7%
25	-2.1%	-3.0%	-3.1%	-2.3%	-3.9%	-3.7%	-3.0%	-2.7%
26	1.5%	3.3%	0.9%	3.9%	3.6%	4.6%	3.0%	3.0%
27	-0.8%	-0.6%	-0.8%	0.3%	0.8%	-0.7%	1.3%	0.5%
28	-5.0%	-3.6%	0.9%	-1.4%	-4.0%	-4.5%	-5.0%	-3.2%
29	-2.7%	-0.6%	-7.1%	-2.7%	-2.9%	-0.9%	-1.3%	1.1%
30	-1.5%	1.6%	1.8%	3.8%	0.9%	3.7%	2.1%	-0.6%
31	-5.8%	-9.7%	-7.6%	-6.8%	-7.9%	-6.3%	-8.0%	-6.8%
32	-3.6%	-1.9%	-1.1%	-4.1%	-5.0%	-1.6%	-3.5%	-5.5%
33	-2.6%	-3.0%	-3.2%	-2.8%	-3.4%	-2.2%	-3.3%	-3.1%
34	-1.8%	1.1%	0.3%	1.3%	1.6%	-2.4%	1.5%	-1.1%
35	-0.3%	0.3%	3.1%	1.3%	1.6%	2.5%	0.6%	3.0%
36	-0.9%	0.7%	0.5%	0.0%	-0.3%	-2.0%	-0.8%	-0.2%
37	-1.2%	2.0%	-0.6%	0.2%	-8.4%	-3.3%	-3.3%	0.6%
38	-6.0%	-5.8%	-8.2%	7.8%	-5.1%	-9.6%	-6.5%	-8.4%
39	-6.1%	-5.9%	-8.6%	-7.6%	1.0%	-7.0%	-5.6%	-7.2%
40	1.4%	5.1%	4.1%	2.7%	2.5%	5.3%	3.5%	3.6%
41	-7.6%	-4.8%	-14.2%	-8.3%	-6.5%	-5.0%	-8.7%	-5.5%
42	**0.8%**	**1.8%**	**-0.3%**	**-0.1%**	**-0.6%**	**-0.7%**	**-1.5%**	**-0.4%**
43	**0.7%**	**0.3%**	**1.0%**	**0.7%**	**-0.6%**	**0.7%**	**0.4%**	**-0.4%**
44	-3.7%	-0.4%	-1.7%	-2.7%	-2.0%	-5.9%	-0.9%	-4.0%
45	0.0%	-4.1%	-1.6%	0.3%	1.9%	-1.8%	-0.9%	-4.8%
46	-4.5%	-3.2%	-2.9%	-4.7%	-4.3%	-3.5%	-1.8%	-3.7%
47	-0.6%	-2.9%	-0.1%	-1.6%	-2.6%	1.2%	-2.7%	-2.1%
48	-0.2%	2.0%	0.7%	0.8%	1.6%	0.6%	0.9%	0.6%
49	-1.7%	0.4%	-0.8%	-0.9%	-1.2%	-2.0%	-0.3%	-1.4%
50	0.8%	0.9%	1.1%	1.2%	1.3%	2.5%	2.1%	1.9%
51	4.5%	1.8%	8.4%	3.9%	5.9%	1.1%	3.7%	2.2%
52	0.0%	-3.3%	-3.8%	-0.3%	-2.6%	-5.6%	0.3%	-3.6%
53	3.2%	6.6%	5.3%	2.9%	4.7%	3.3%	9.1%	1.8%
54	0.0%	1.0%	-1.8%	0.8%	-1.5%	1.7%	-1.0%	1.0%
55	**0.8%**	**0.5%**	**0.7%**	**0.6%**	**0.4%**	**0.8%**	**0.5%**	**0.2%**
56	0.3%	-1.3%	0.6%	-0.8%	-1.2%	0.7%	0.1%	0.4%
57	-5.9%	-0.8%	-0.5%	0.0%	0.5%	0.5%	1.8%	2.5%

5.2.2 Temperature resistance test

The temperature resistance test of the optical fiber feed through was carried out up to 200 °C by putting it in the oven. Three cycles of the test were carried out with the temperature ramp rate of >20 °C/hr. Temperature of the feed through was measured by a thermocouple as shown in Fig. 5.2-3. The thermocouple was attached just near the one of the feed through channels it self. The measured result of the temperature and the picture of the feed through acomodated in the oven are shown in Fig. 5.2-4 and 5.

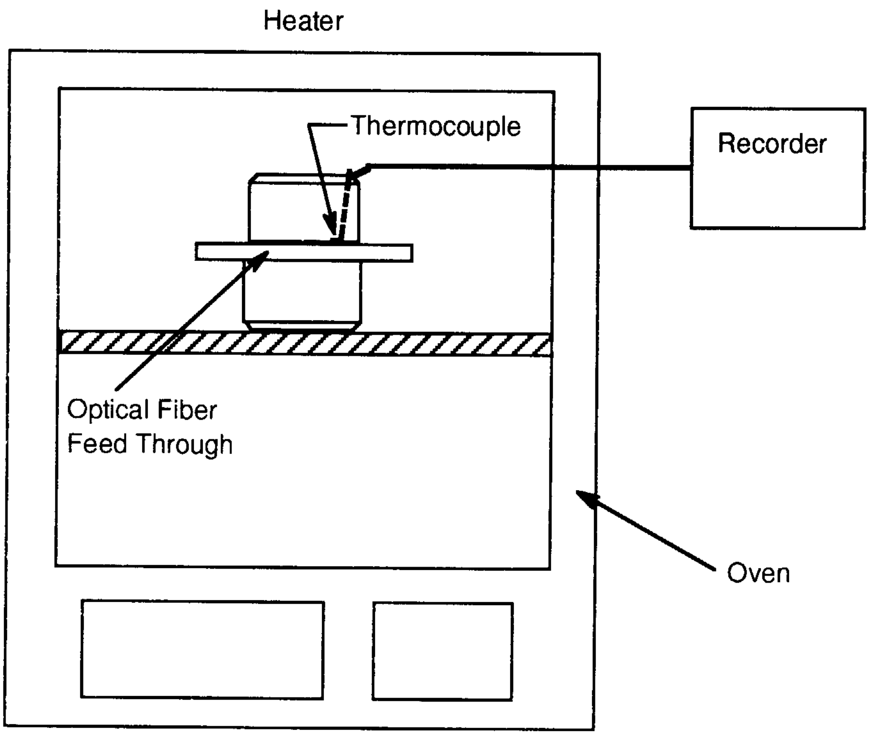


Fig. 5.2-3 Arrangement of the temperature resistance test.

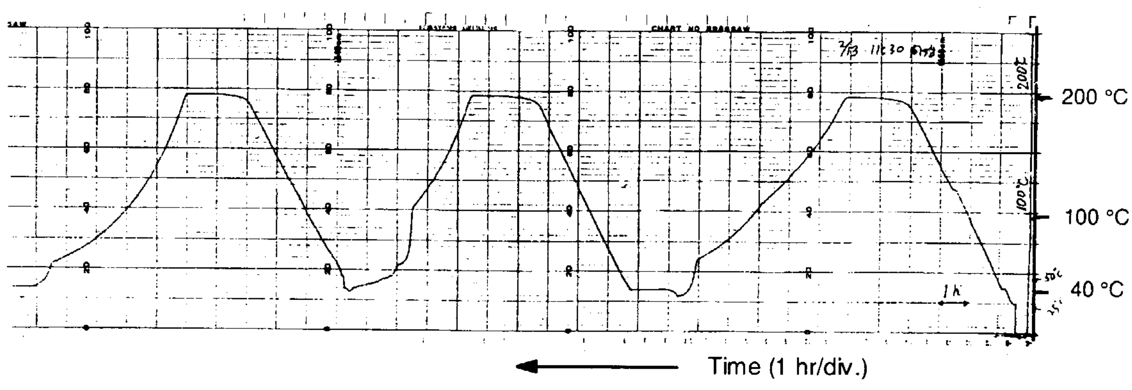


Fig. 5.2-4 Chart of the temperature of the heat cycle. The temperature was measured by a thermocouple attached just near the one of the feed through channels it self.

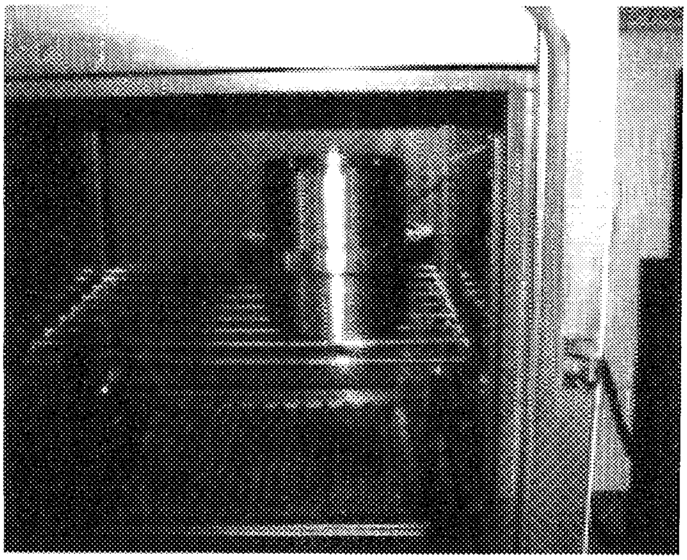


Fig. 5.2-5 Feed through acomodated in the oven.

5.2.3 Acceleration test

The acceleration test of the optical fiber feed through was carried out in the condition of 15 g (10 ms, 1000 cycles) along the three different directions crossing at right angles. The arrangement of the testing instrument is shown in Fig. 5.2-6.

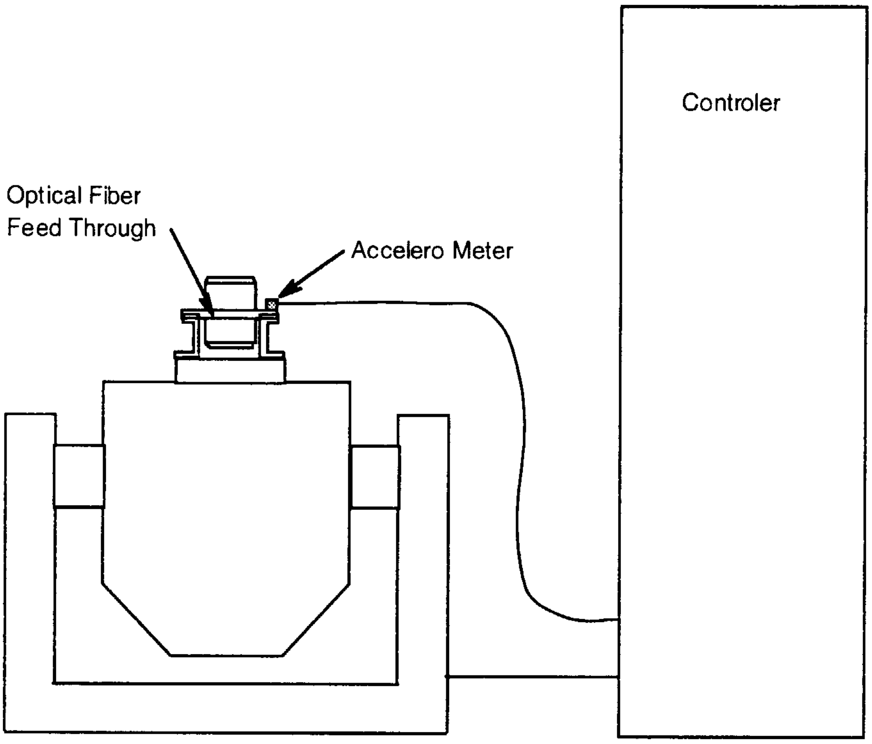
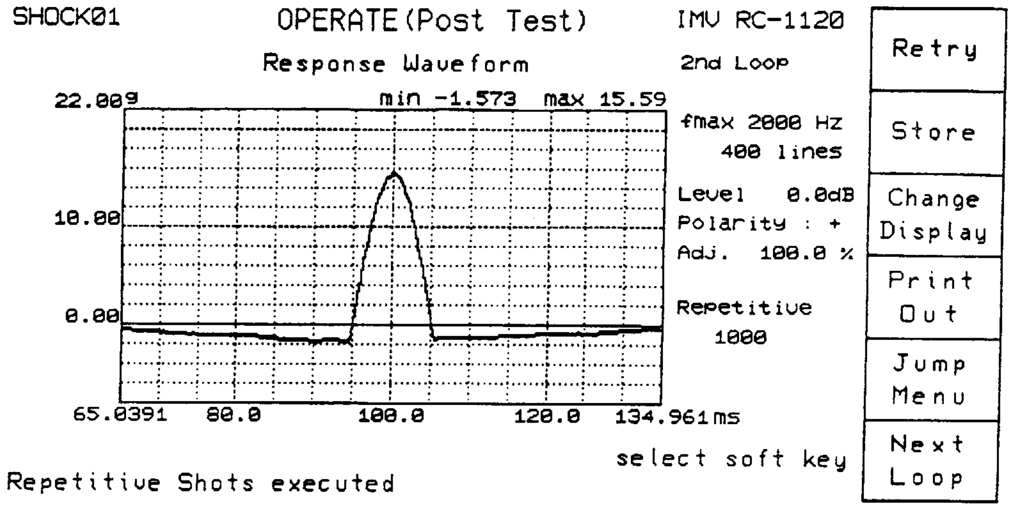


Fig. 5.2-6 Arrangement of the acceleration test of the optical fiber feed through.

The charts of the acceleration tests along the three different directions crossing at right angles and the pictures are shown in Fig. 5.2-7(a), (b) and (c).



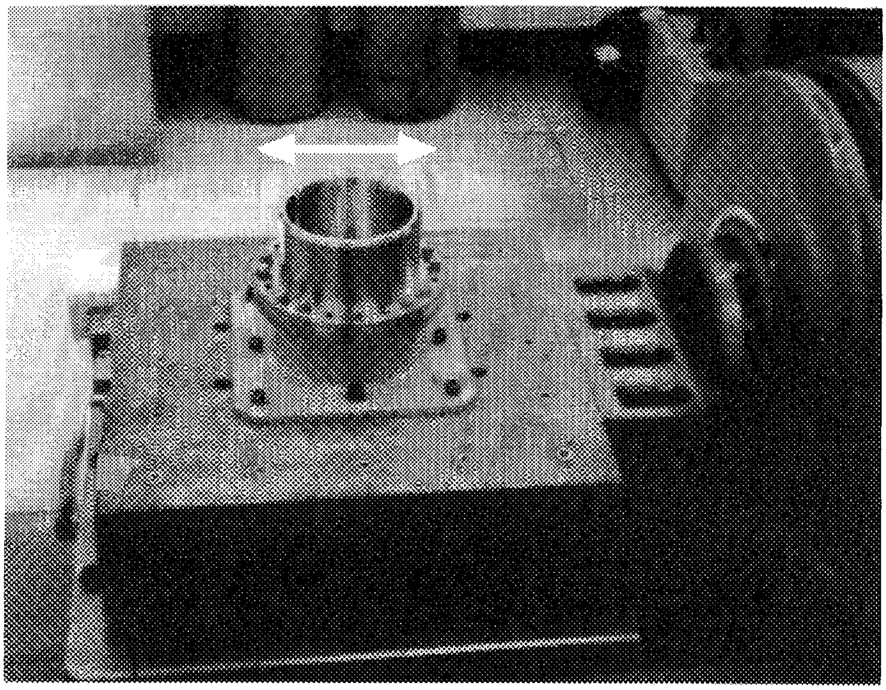
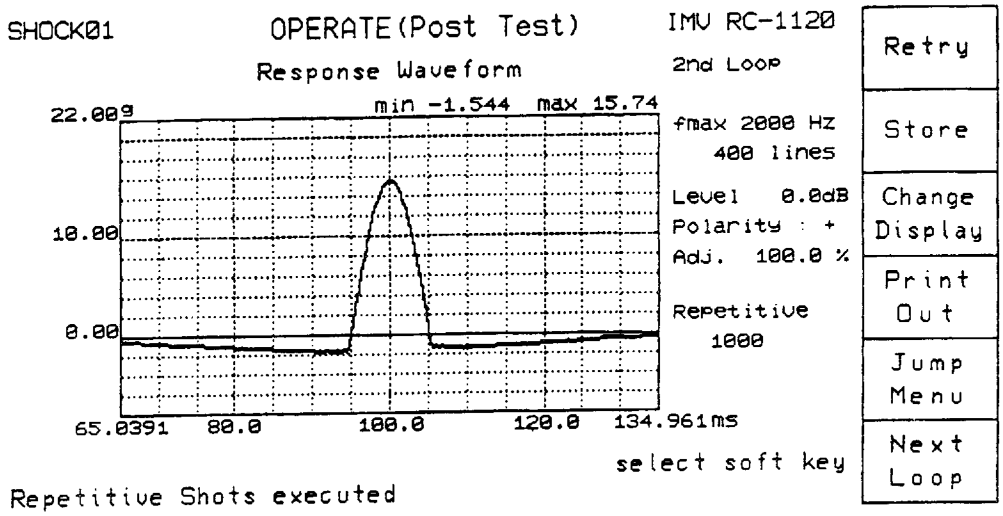


Fig. 5.2-7(a) Chart of the acceleration test along the direction of X, and the picture of the test.



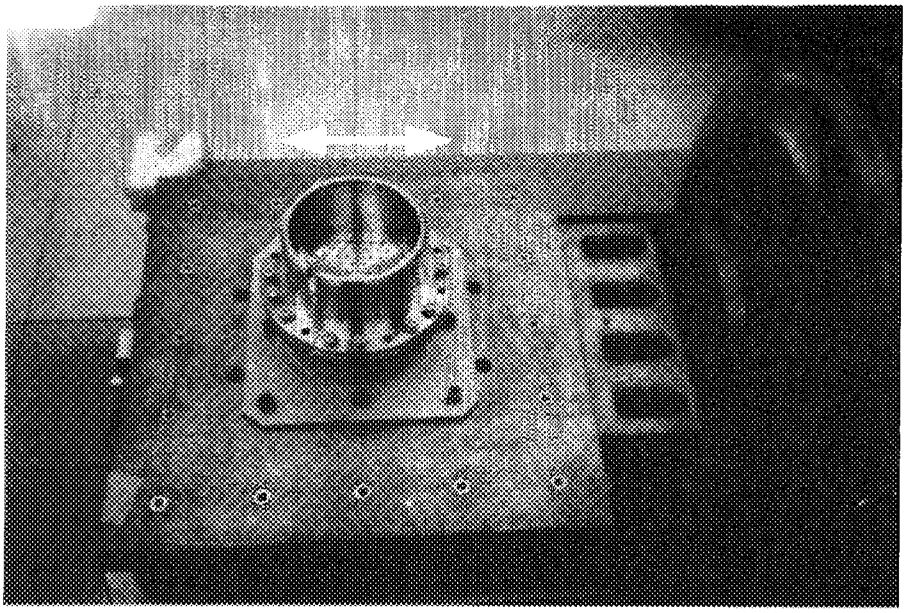
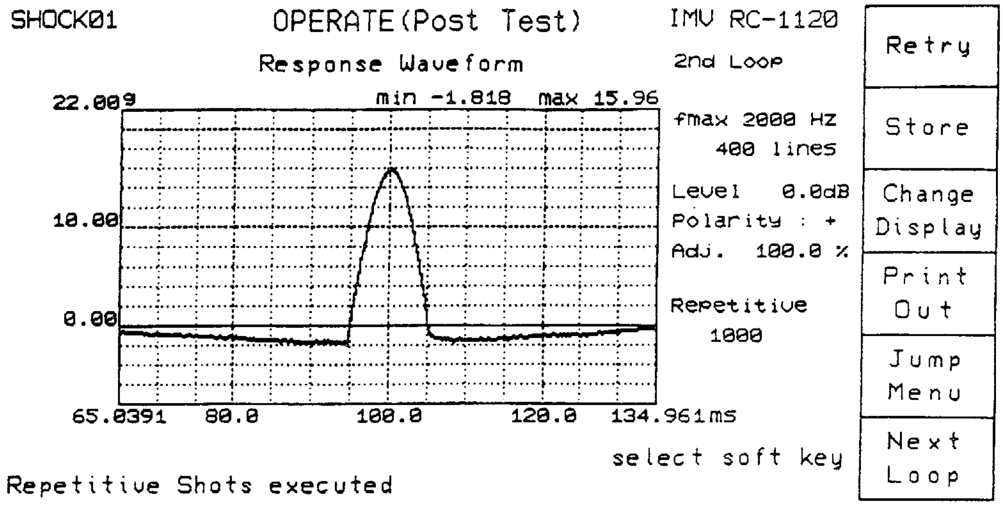


Fig. 5.2-7(b) Chart of the acceleration test along the direction of Y, and the picture of the test.



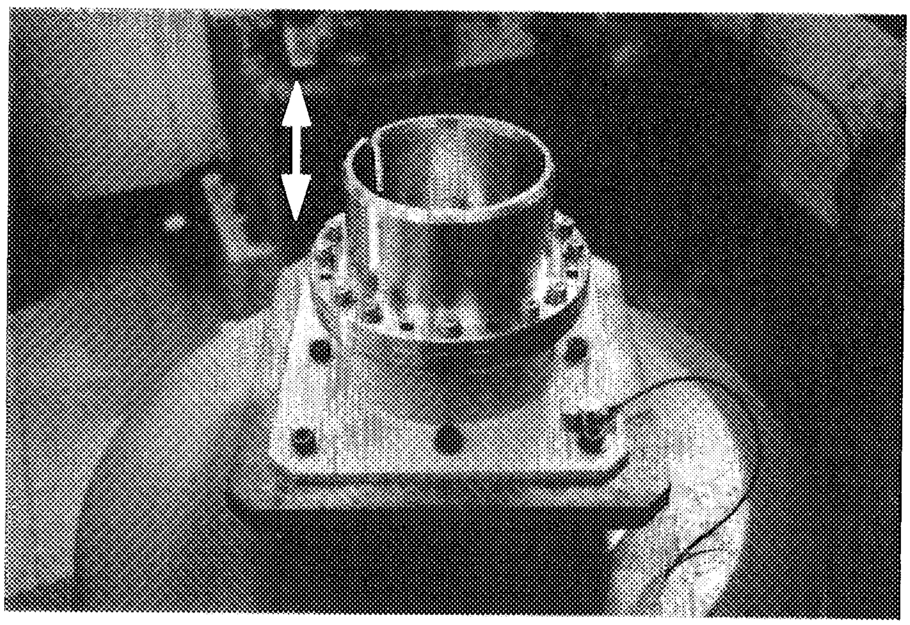


Fig. 5.2-7(c) Chart of the acceleration test along the direction of Z, and the picture of the test.

5.2.4 Pressurization test

The pressurization test of the optical fiber feed through was carried out in the condition of up to 5 bar (5×10^5 Pa) by nitrogen gas. The arrangement of the test is shown in Fig. 5.2-8. The pictures of the test are also shown in Fig. 5.2-9. There were no trouble during this pressurization test. The requirement of 2 bar was satisfied sufficiently.

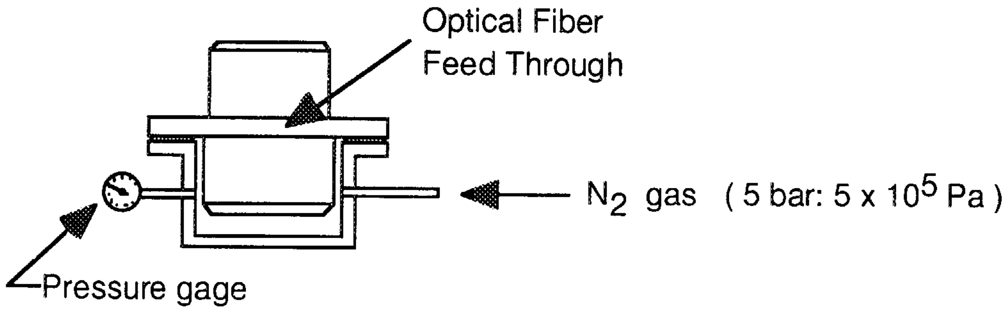


Fig. 5.2-8 Arrangement of the pressurization test of the optical fiber feed through.

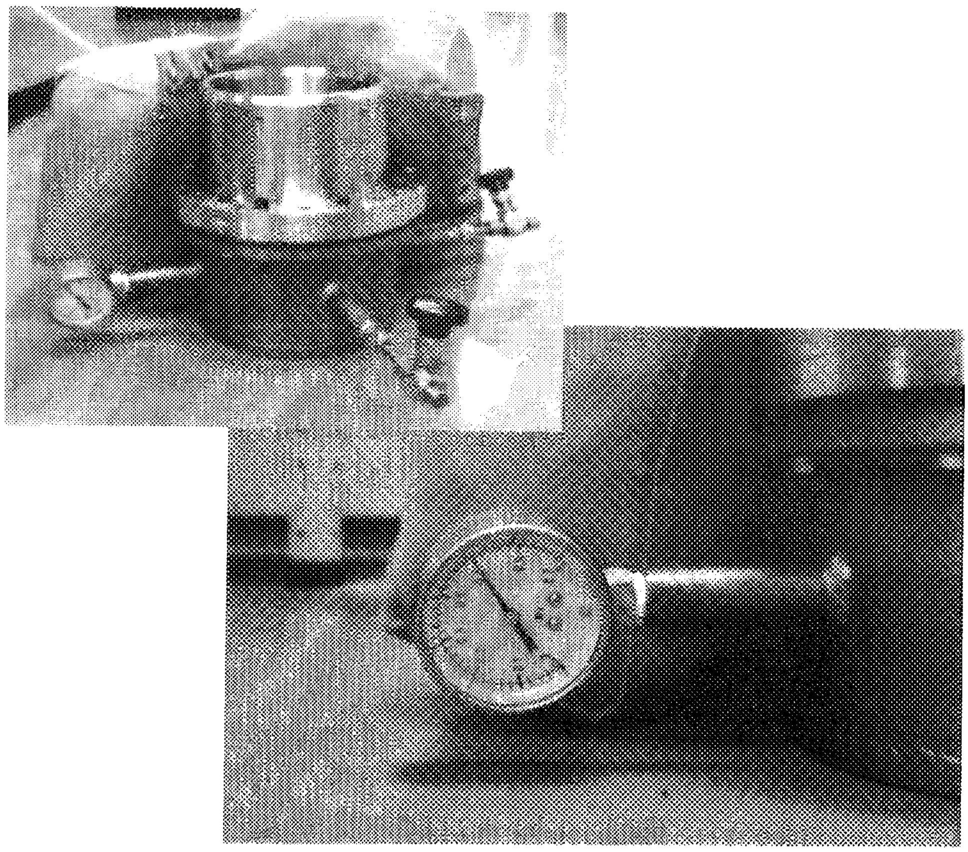


Fig. 5.2-9 Pictures of the test. The optical fiber feed through was pressurized up to 5 bar (5×10^5 Pa) by nitrogen gas.

5.2.5 Vacuum leak test

The vacuum leak test of the optical fiber feed through was carried out before and after the temperature resistance test, the pressurization test and the acceleration test by a He-leak detector calibrated with standard leak of 1.8×10^{-9} Pa m^3/s.

The arrangement of the test is shown in Fig. 5.2-10. The leak was lower than the detection limit of 5×10^{-12} Pa m^3/s before the temperature resistance test, the pressurization test and the acceleration test. The chart of the leak test after those test is shown in Fig. 5.2-11. The leak was not detected as shown in the chart. The requirement of $< 1 \times 10^{-10}$ Pa m^3/s was satisfied sufficiently.

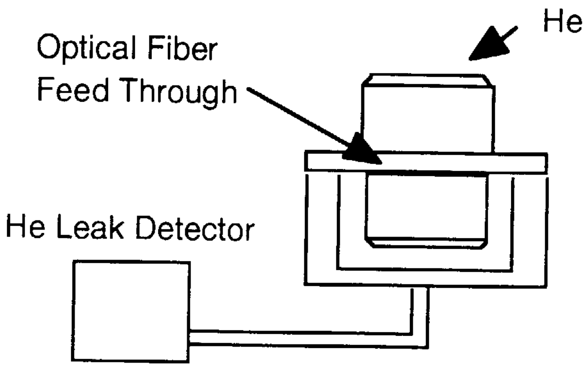


Fig. 5.2-10 Arrangement of the vacuum leak test of the optical fiber feed through.

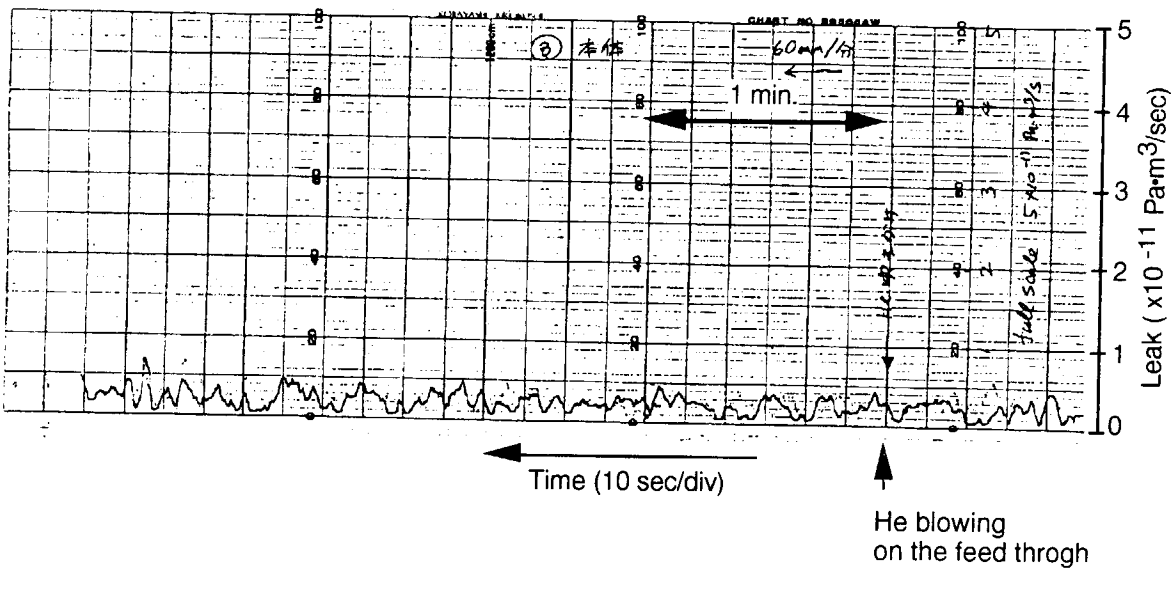


Fig. 5.2-11 Chart of the leak test after the temperature resistance test, the pressurization test and the acceleration test.

5.3 **Evaluation** (Full performance test-module)

The full performance test-module which has 57 fiber feed throughs in the vacuum flange was manufactured and tested. The result of the full performance test-module comparing with the requirements is summarized as Table 5.3-1.

Table 5.3-1 Achieved values of full performance test-module comparing with required values.

Required item	Required value	Achieved value
Material of fiber core	Fused quartz	Fused quartz
Material of fiber core	200 μm	200 μm
Diameter of fiber core	> 50	53
Vacuum Seal	He Leak < 1 x 10^{-10}Pa m^3/s	He Leak < 5 x 10^{-12}Pa m^3/s
Capacity to Resist Inner Pressure Rise	> 2 atm (2 bar, 2 x 10^5 Pa)	5 atm (5 bar, 5 x 10^5 Pa)
Mechanical acceleration of structure	> 15g, (duration 10 ms, 1000cycles)	~ 15g, (duration 10 ms, 1000cycles)
Temperature	20°C- 200°C	40°C- 200°C
Temperature ramp rate	> 20°C/hr,	> 20°C/hr,
Uniformity among each channels	> 60 %	61.7 %
Maximum connecting loss per channel	3 dB	2.8 dB

The requirements were almost satisfied. Concerning the connecting loss and the uniformity, the requirements were satisfied by improving the vacuum sealing method at each optical fiber feed through. The temperature resistance test was carried out from 40 °C to 200 °C, unfortunately, because of the limitation of the temperature range of the oven.

The design is not optimized for remote handling. The improvement of the design should be necessary for remote handling treatment.

6. Conclusion

A multi-channel fiber feed through has been developed for visible and IR transmission lines through secondary vacuum boundary (cryostat boundary) of ITER.

In the first phase, a scale down test-module which has ten fiber feed throughs in the vacuum flange was manufactured and tested. The vacuum seal was realized by soldering gold plated fibers to a vacuum flange with high temperature solder. The capacity to resist inner pressure rise of 5 bar (5×10^5 Pa), the acceleration resistant of 15 g and the temperature resistant from 20 °C - 200 °C were achieved by the test module. The connecting loss and the uniformity of transmission losses among each channels of the feed through was not well. Concerning the connecting loss, the best value was 2.2 dB and the worst one was 13.5 dB.

In the second phase, the full performance test-module which has 57 fiber feed throughs was manufactured and tested. The feed through was improved in order to achieve a good transmission and the uniformity among each channels by using a optical fiber implanted in a center of a quartz rod very accurately. The capacity to resist inner pressure rise of 5 bar (5×10^5 Pa), the acceleration resistant of 15 g and the temperature resistant from 40 °C - 200 °C (Temperature ramp rate: > 20°C/hr) were achieved by the full performance test-module. The connecting losses of the feed throughs were less than 3 dB, and the uniformity of transmission losses among each channels of the feed through was larger than 60 %. The requirements for a optical-fiber feed through were almost satisfied with the full performance test-module.

Further improvements and R & D for the optical fiber feed through are expected before manufacturing an actual module for ITER as follows.

i) To reduce the connecting loss.
ii) To increase the uniformity.
ii) To improve the reproducibility of connecting a connector and a feed through.
iii) To reduce the size.
iv) To improve the design for remote handling treatment.
v) Actual test of remote handling treatment with a test module.
vi) Neutron and γ-ray irradiation test.

In addition, it will be favorable to develop the other method which separates the part of the connector from the feed through as same as the electric feed through of ITER.

Acknowledgment

The authors are grateful to Drs. K. Ebisawa, A. Costley and S. Yamamoto for their fruitful discussions and cooperation and to the members of Fujikura Ltd. for their marvelous manufacturing. This paper has been prepared as an account of work assigned to the Japanese Home Team under Task Agreement numbers S 55 TT 07 96-12-09 FJ within the Agreement among the European Atomic Energy Community, the Government of Japan, the Government of the Russian Federation, and the Government of the United States of America on Cooperation in the Engineering Design Activities for the International Thermonuclear Experimental Reactor ("ITER EDA Agreement") under the auspices of the International Atomic Energy Agency (IAEA).

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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

$1\ eV = 1.60218 \times 10^{-19}\ J$

$1\ u = 1.66054 \times 10^{-27}\ kg$

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

$1\ Å = 0.1\ nm = 10^{-10}\ m$

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

$1\ bar = 0.1\ MPa = 10^5\ Pa$

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

$1\ Ci = 3.7 \times 10^{10}\ Bq$

$1\ R = 2.58 \times 10^{-4}\ C/kg$

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

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

(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

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

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

動粘度　$1\ m^2/s = 10^4 St$(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

$J(=10^7\ erg)$	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)

DEVELOPMENT OF MULTI-CHANNEL OPTICAL-FIBER FEED THROUGH FOR ITER