3. Experimental Facility for JEM

3.1 Study of On-Board Experiment Cell with Fluid Physics Experiment Facility (FPEF)

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STUDY OF ON-BOARD EXPERIMENT CELL WITH FLUID PHYSICS EXPERIMENT FACILITY (FPEF)

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As a continuation of the studies performed in the previous fiscal year, the study of feasibility of conducting the dynamic surface deformation measurement on the liquid bridge with various of diameter, to be utilized for the Liquid Bridge Marangoni Convection Experiments using the JEM Fluid Physics Experiment Facility (FPEF), was performed. From these studies, compatibility with the FPEF and the items to be developed were shown. One of them is the method to seal the sample or tracers for the small diameter liquid bridge formation equipment. Some of the methods to seal the sample and tracers have been proposed. Test plan using the Bread Board Model (BBM) of small diameter (5mm) liquid bridge formation equipment was established to study them. BBM was designed and constructed based on the test plan, and then BBM tests were performed. Test results showed the feasibility of small diameter liquid bridge formation equipment for Marangoni Convection Experiments.

1. INTRODUCTION

Even though the small diameter liquid bridge formation equipment is a new development item, most of all design idea for the current test-cell (30mm diameter) could be utilized on it. However, some points, such as the way to seal the sample or tracers, are different from the current test-cell because of its small cooling disk as shown below.

- Sealing O-ring cannot be placed on the cooling disk
- Sample cassette system cannot be used because of sealing method

These difference lead difficulties not only sealing but also performance of forming the liquid bridge without bubble.

On the other hand, the development cost should be minimized. The ways to reduce the cost are, utilizing commercial products, conducting BBM tests to confirm the performance of the commercial products or eliminating the difficulty of development using BBM test results. BBM test plan should be established to study how to seal the sample and tracers without bubble contamination, tracer clogging or miss send-out. Reliability of the system, including the performance of forming the liquid bridge, must be confirmed on BBM tests even if the commercial products are installed.

2. STUDY OF THE EXPERIMENT CELL

2.1 Sealing method option

There are seven options of sample/tracers sealing method on the cooling disk of the small diameter liquid bridge formation equipment as shown below.

Table 2.1-1 Various type of sample seal method for small diameter liquid bridge formation equipment

No.	Name	Feature
1	Ball seal type	Set a small rubber ball on the sample send-out hole for sealing. The ball will be removed by needle on the heating disk at orbit. Rupture film type is the same concept. Merit: Similar concept as O-ring (current design). Demerit: Poor reliability for sealing or unsealing. Small ball could be remained on the disk.
2	Inner ball seal type	Check valve inside the cooling disk. Disk movement releases the sealing ball automatically. Merit: Good sealing ability. Demerit: Complicated mechanism in the small diameter disk. Possibility of bubble contamination because of complex tracer path.
3	Inner O-ring type	Install an O-ring inside the cooling disk. Disk movement releases the sealing ball automatically. Merit: Good sealing ability. Demerit: Complicated mechanism in the small diameter disk. Possibility of bubble contamination because of complex tracer path, such as a spring.
4	Manual valve type	Place a manual valve between the cooling disk and pump. Merit: Good sealing and high reliability. Demerit: Need clew operations. Long tracer path.
5	Inert valve type	Install an inert valve inside the cooling disk. Merit: Since the tracers can go through the valve, good sealing of tracer. Demerit: Valve is not small. Cooling ability must be considered. Long tracer path.
6	On/Off valve type	Install a micro on/off valve (diameter 5mm) inside the cooling disk to seal the sample and the tracers. Merit: Short tracer path. Demerit: Possibility of clogging of the tracers in the valve.
7	Cap seal type	Using same valve as No.6 idea. Placing a filter lower than the micro valve for the tracers. Cap or heating disk will be utilized as a seal for tracers. Merit: Very short tracer path. Demerit: Cap seal needs clew operation. Need consideration to prevent disk edge damaging if heating disk is used for seal.

Figure 2.1-1 through 2.1-7 show each idea.

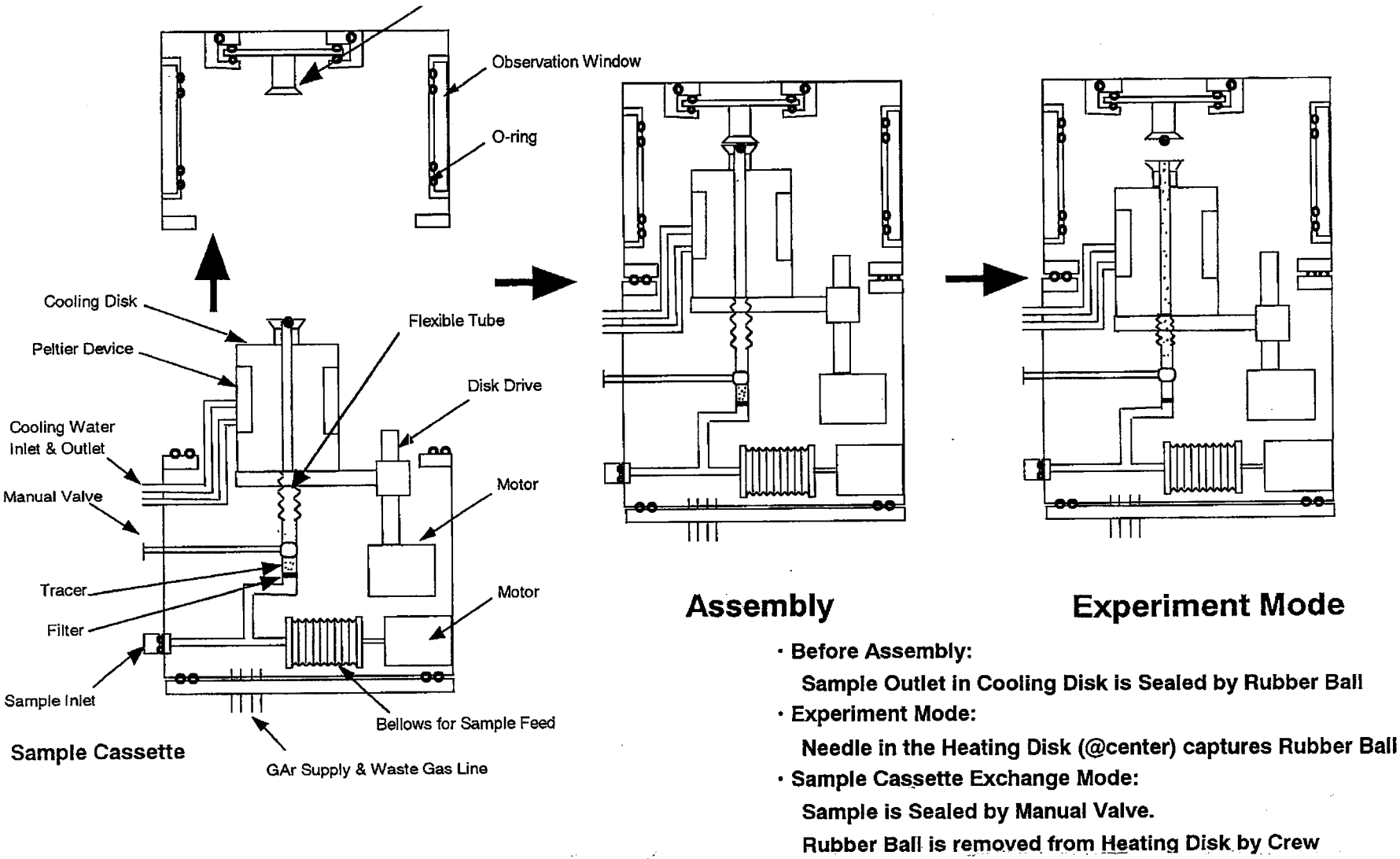


Figure 2.1-1 Ball seal type

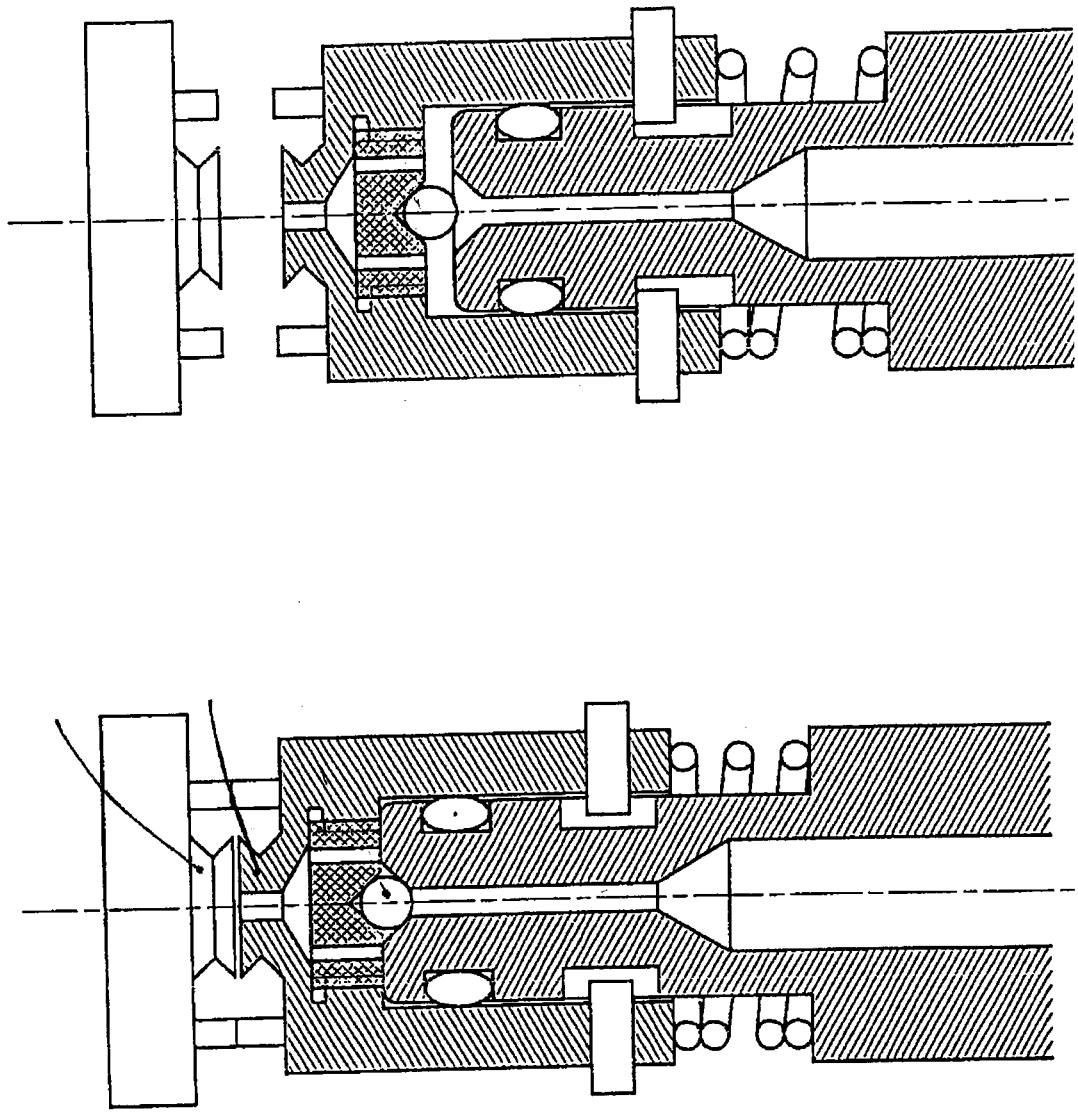


Figure 2.1-2 Inner ball seal type

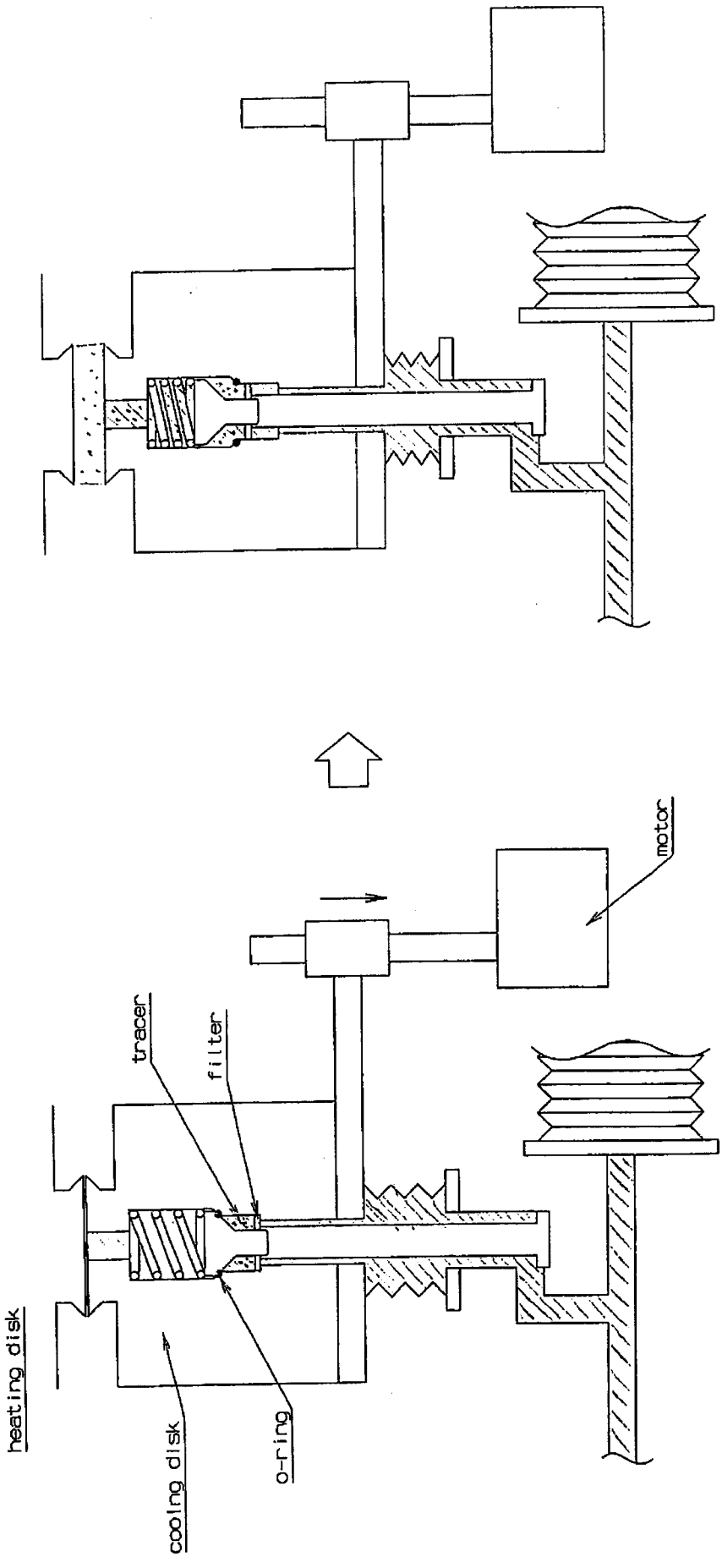


Figure 2.1-3 Inner O-ring type

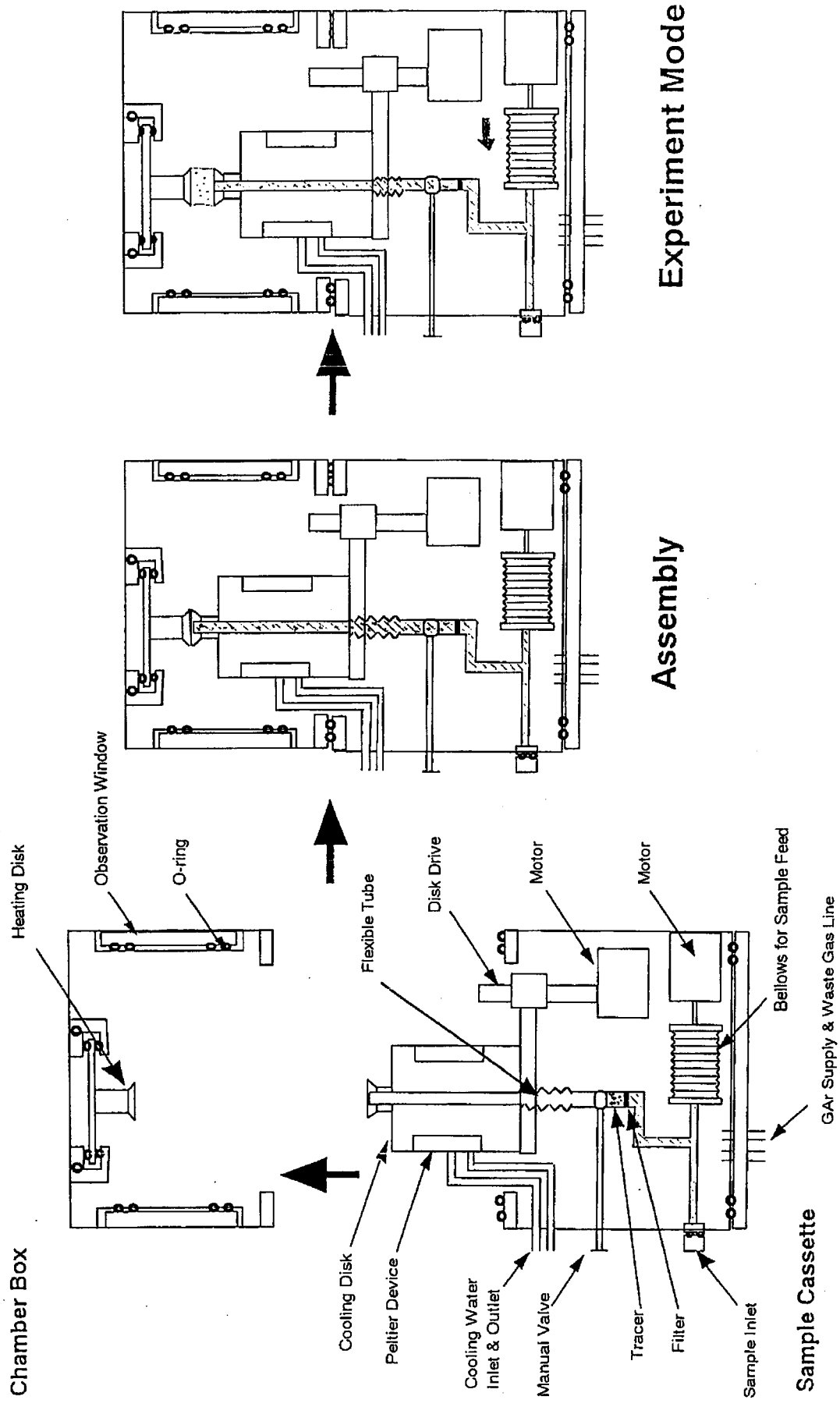
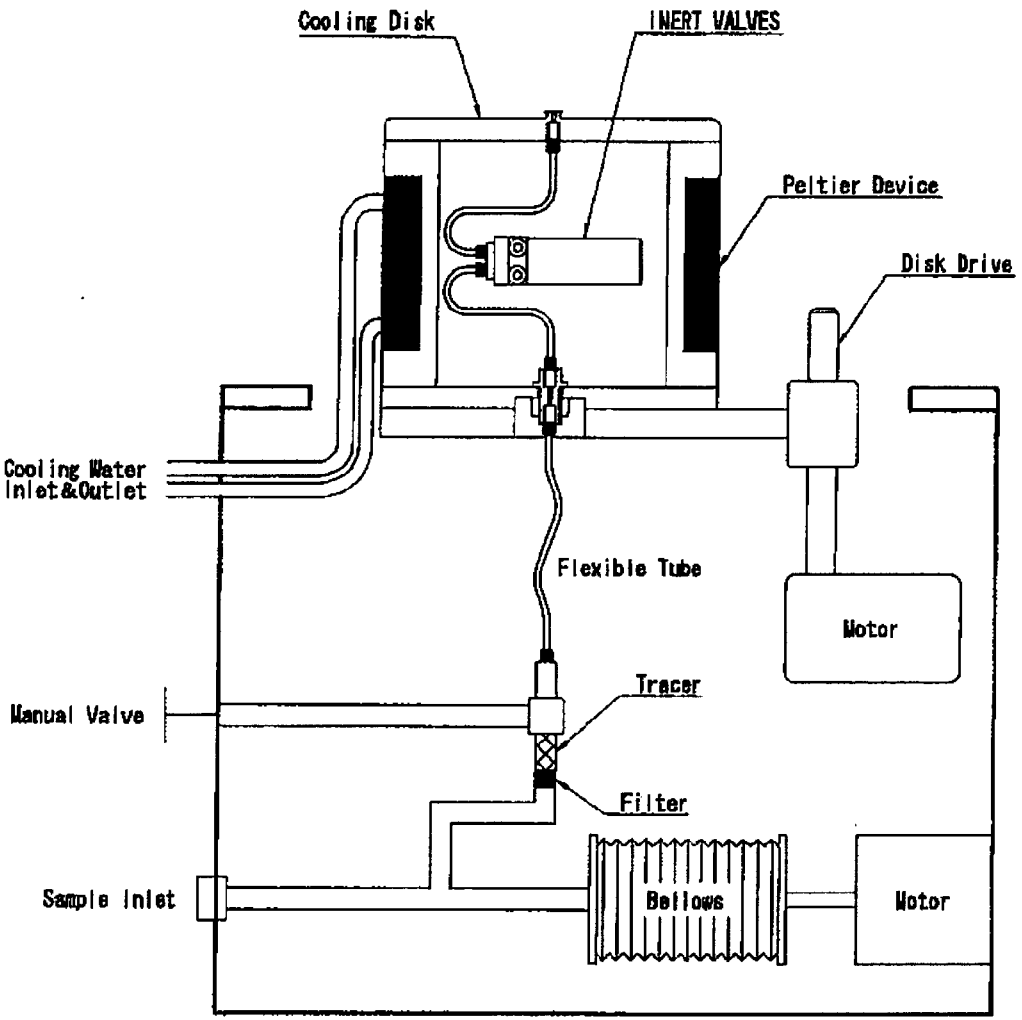


Figure 2.1-4 Manual valve type



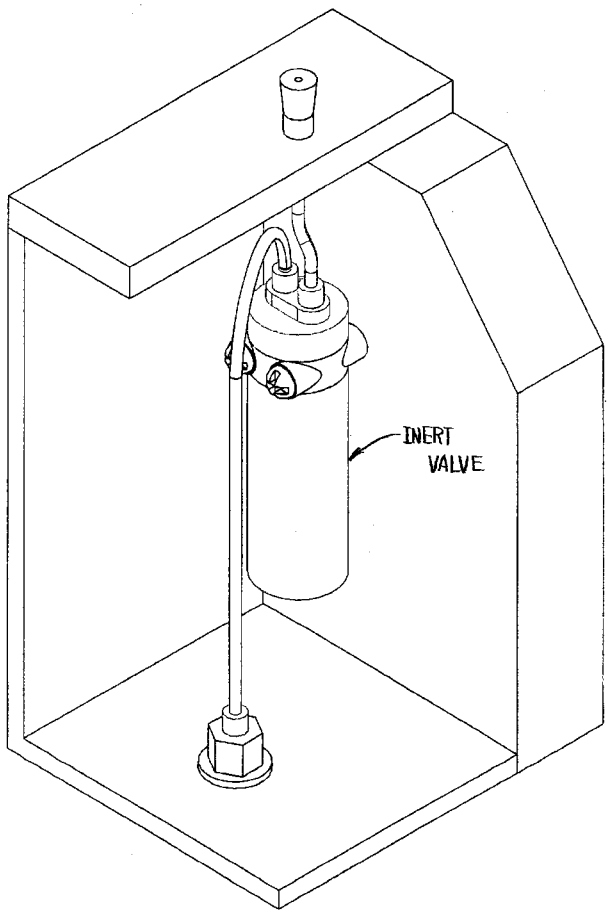
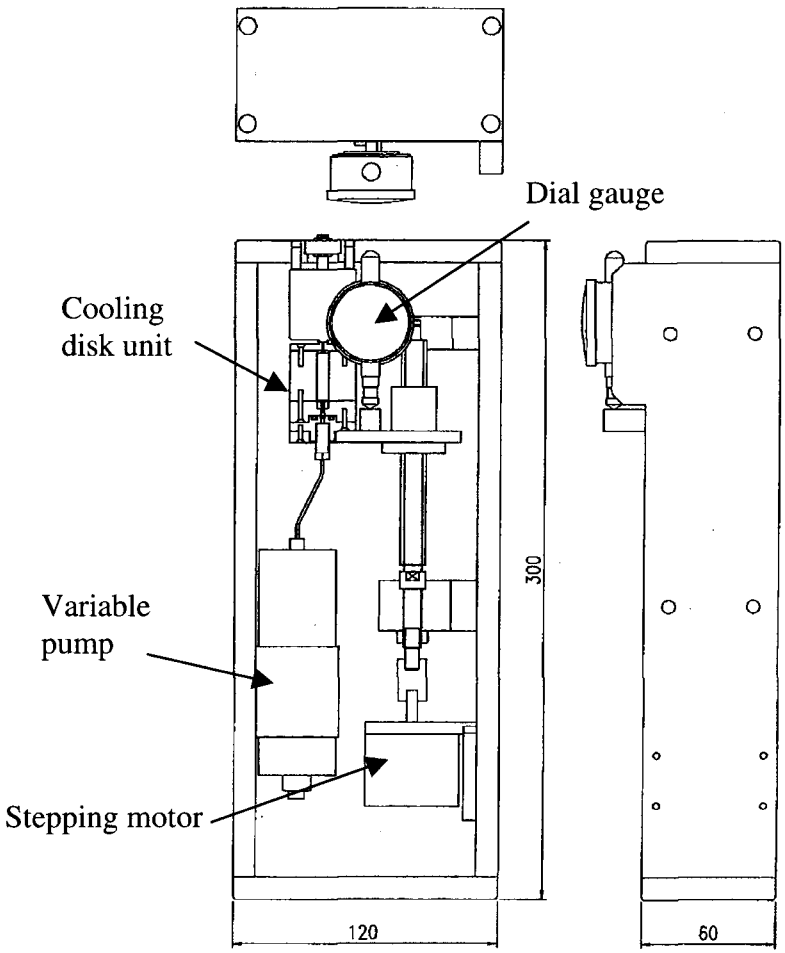


Figure 2.1-5 Inert valve type



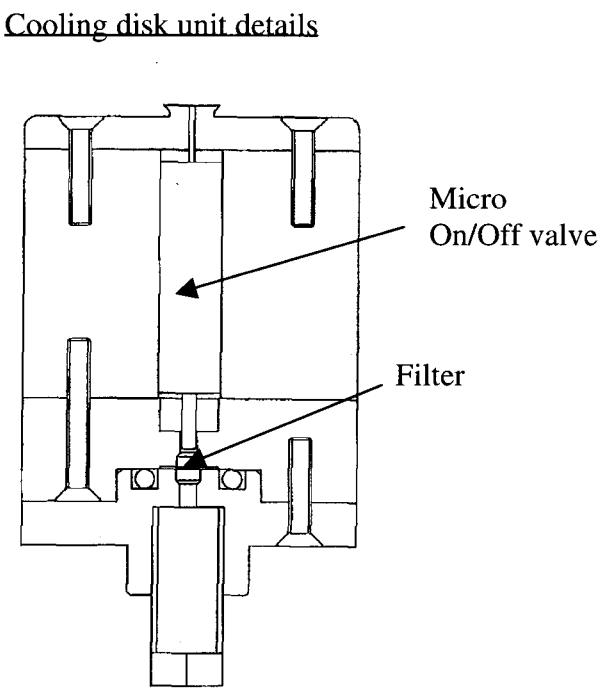
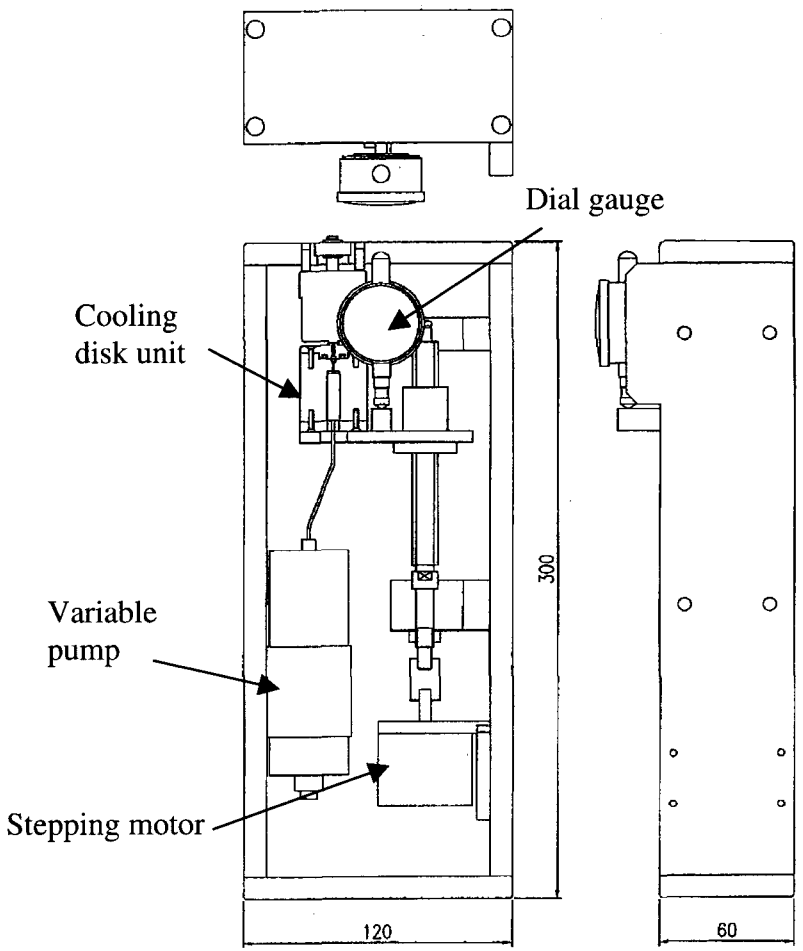
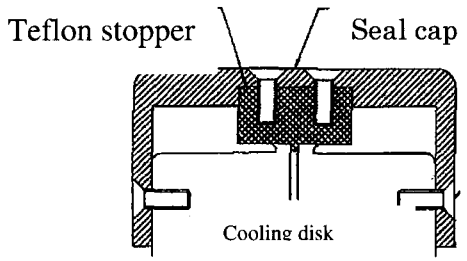


Figure 2.1-6 On/Off valve type





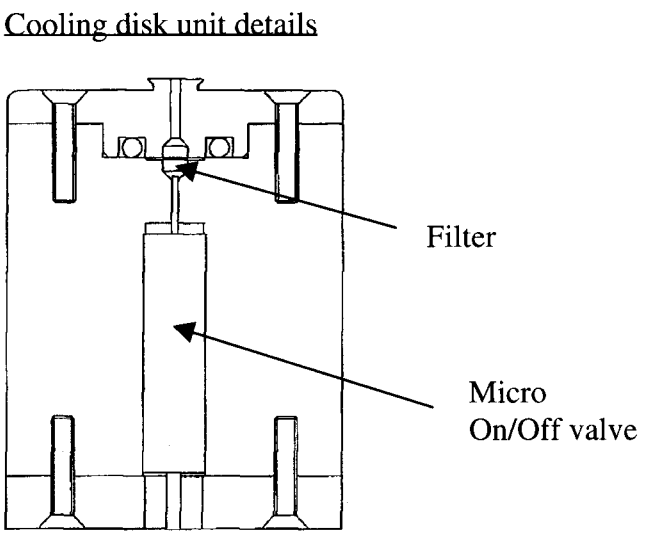


Figure 2.1-7 Cap seal type

Table 2.2-1: Trade-Off Score for sample sealing method

	Ball seal type		Inner ball seal type		Inner O-ring type		Manual valve type		Inert valve type		On/Off valve type		Cap seal type	
Tracer path (5)	Simple Long	2	Complicated Long	1	Complicated Not long	2	Simple Long	2	Simple Long	2	Simple Short	5	Simple Short	5
Sealing (5)	Bad	2	Not bad	4	Not bad	3	Good	5	Good	5	Not bad	4	Good	5
Sensor for the disk (3)	No Problem	3	Difficult	1	Difficult	1	No problem	3	No problem	3	No problem	3	No problem	3
Total (13)	Difficulty for seal using small ball	7	Long and complicated tracer path	6	Complicated tracer path and difficulty of disk sensor	6	Long tracer path	10	Long tracer path	10	Depend on adaptation between the tracer/ valve	12	Shortest tracer path	13

2.2 Trade off study

Since the shortest liquid bridge of the 5mm-diameter liquid bridge length is 1.5mm, the smallest amount of sample is 29.5mm^3. That means the tracer path must be short as possible, less than 29mm^3 volume. To prevent bubble, sample path lower than the seal should be simple.

To select the sealing method for the BBM, trade off study is performed. Trade off score is shown in Table 2.2-1. At this study, score is focused on the three items as tracer's path, sealing performance and setting flexibility of sensors (thermocouple).

As a result of this trade off study, we chose the On/Off valve type and the Cap seal type as the BBM.

2.3 BBM design outline

Concept of the BBM is shown in figure 2.1-6 or 2.1-7. Both types of cooling disk unit (micro valve, tracer filter and cooling disk) will be prepared and be exchanged for the common parts of the BBM such as pump, frame or heating disk.

Commercial variable volume pump is adopted as a sample dispenser. Figure 2.3-1 shows the outline of the pump. Sample will be sealed by commercial micro valve shown in Figure 2.3-2. Both commercial products' specifications are described below.

Variable Pump

Supplier	LEE Corporation
Volume of Sample	250 mm^3
Minimum Dispense	0.5 mm^3
Vacuum/Supply Pressure	-68/103 kPa
Weight	285 g
Port	2 Ports Type

Micro Valve (or On/Off Valve)

Supplier	LEE Corporation
Diameter (max)	5.6 mm
Length (max)	31.4 mm
Output Port Diameter	0.5 mm
Pressure range	0 – 68kPa
Open/Close	Normal Close Type

Stepping motor will drive the cooling disk unit. Displacement information of the cooling disk will be given manually using dial gauge. Disk, pump and valve will be controlled by same software and should be linked each other.

Actual BBM outline and test conditions are shown in Figure 2.3-3 through 2.3-6. CCD camera with macro-lens was used to observe the tracers and/or displacement of liquid bridge's edge when volume of sample is adjusted.

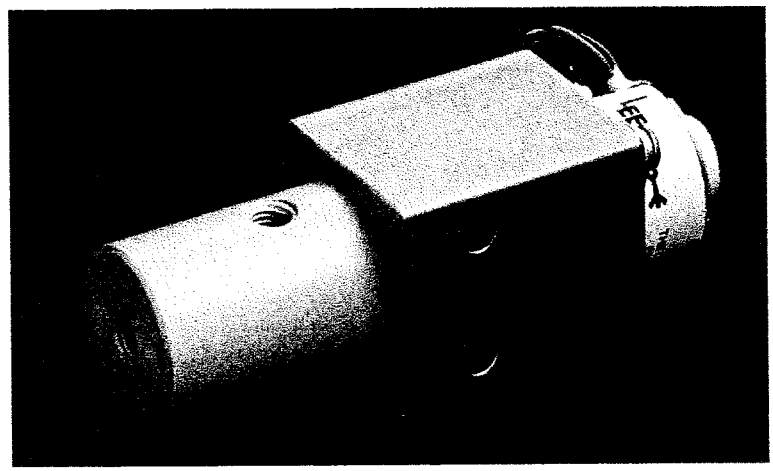


Figure 2.3-1(a) Outline of variable volume pump

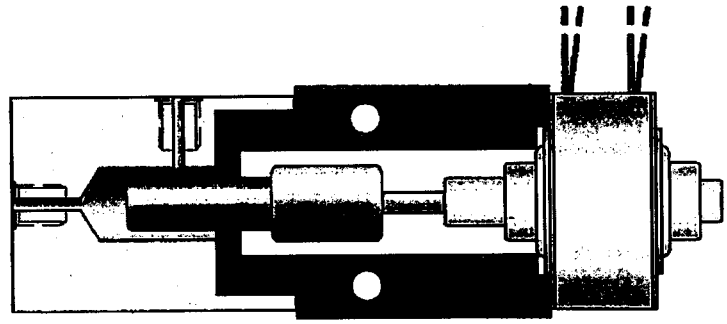


Figure 2.3-1(b) Cut image of variable volume pump

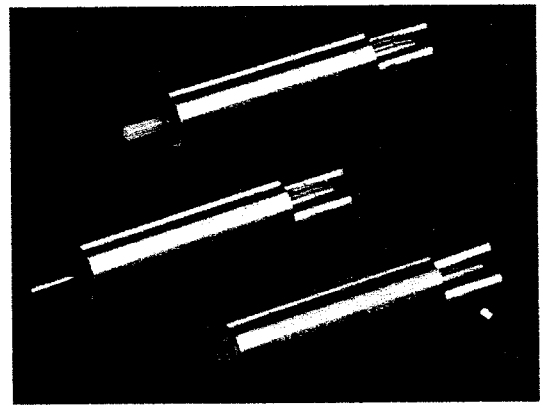


Figure 2.3-2(a) Outline of micro valve

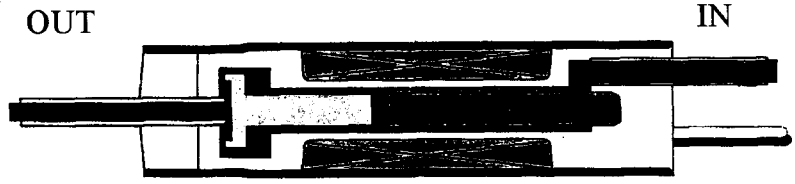


Figure 2.3-2(b) Cut image of micro valve

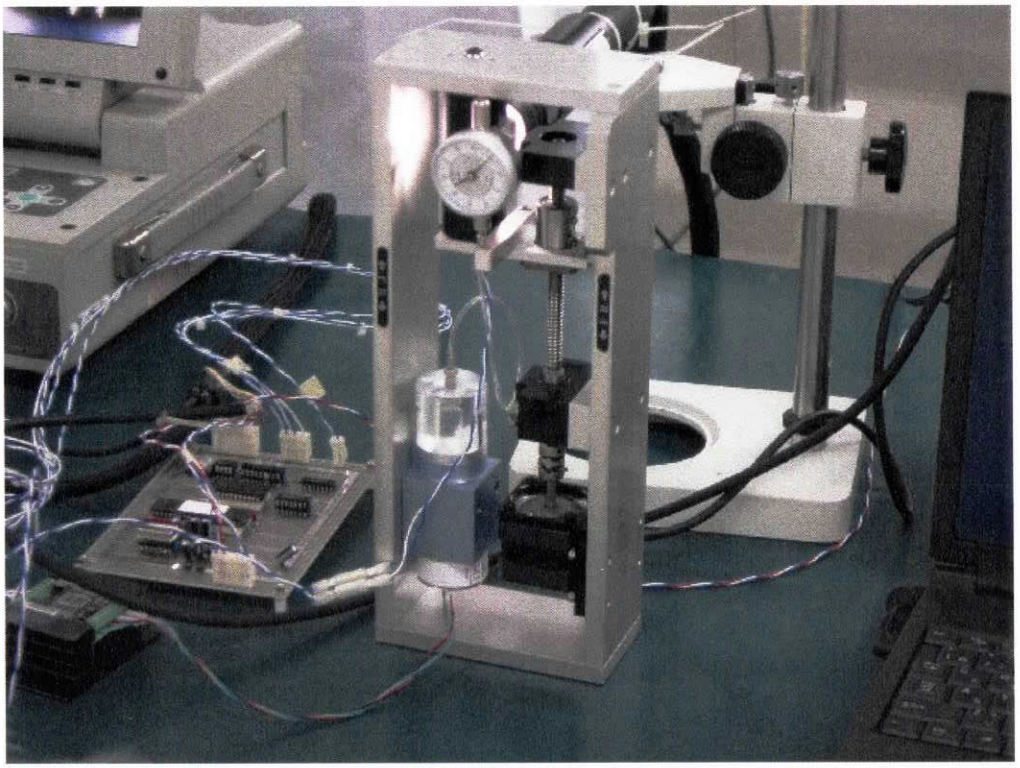


Figure 2.3-3 Outline of BBM

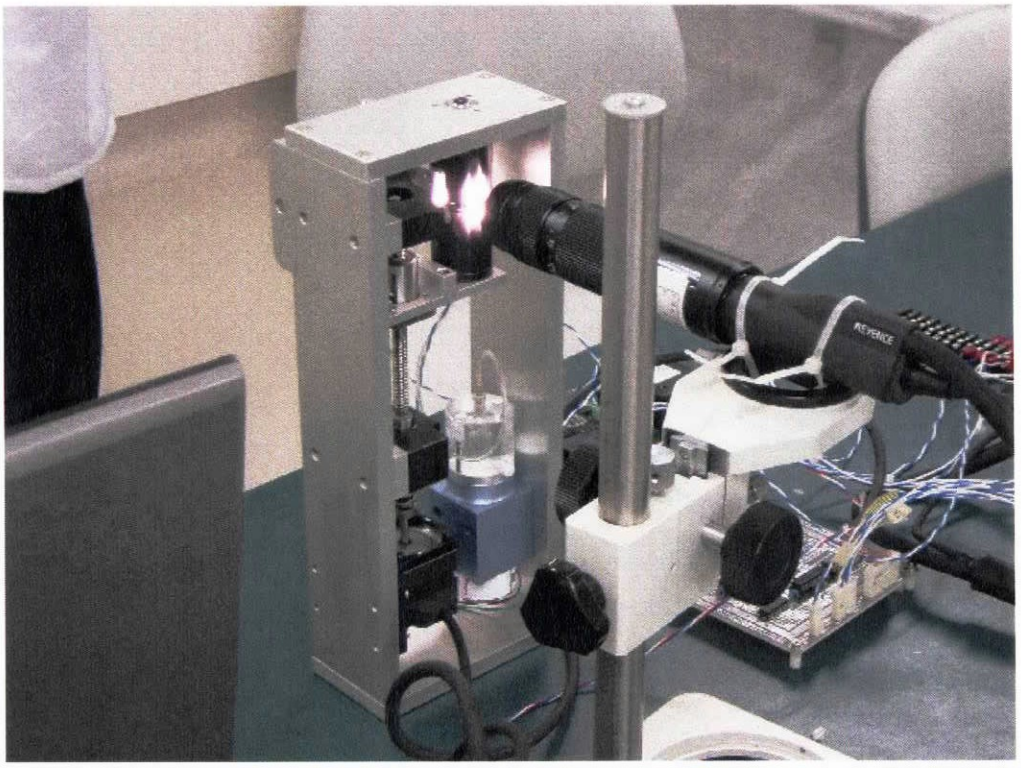


Figure 2.3-4 BBM test configuration

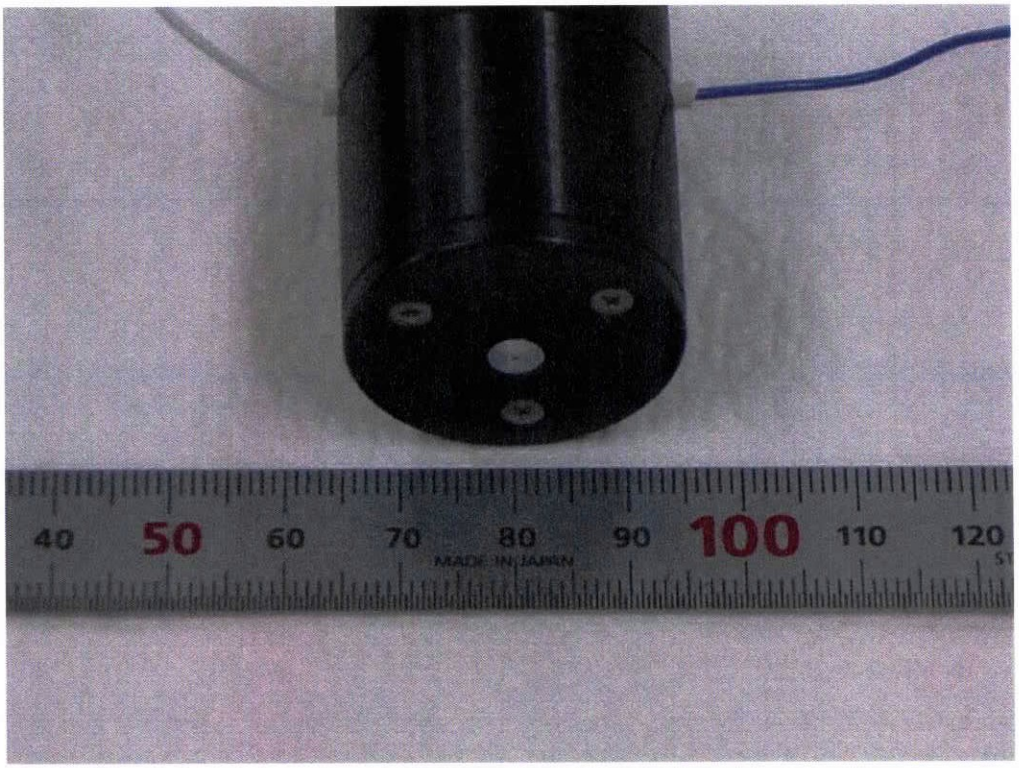


Figure 2.3-5 Cooling disk of BBM

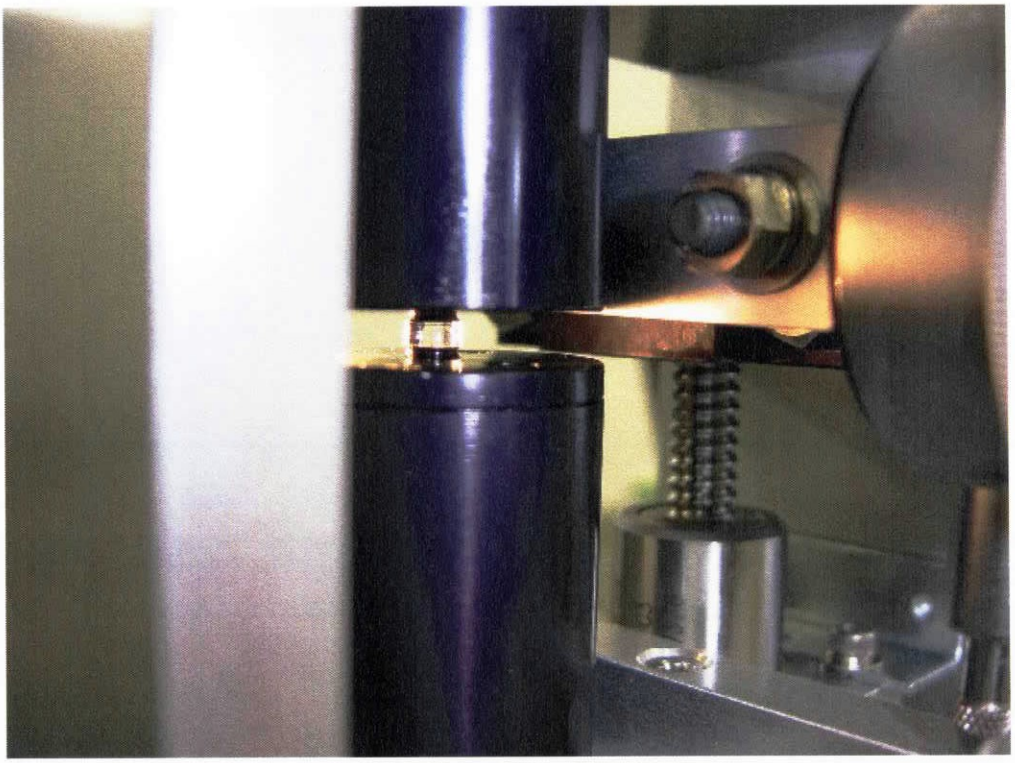


Figure 2.3-6 Small liquid bridge formation test

2.4 BBM test items

Test items are set as shown below. There are 3 categories, 7 items. The BBM is designed to test and confirm these items.

(1) Sample seal
  (a) Bubble contamination
  (b) Sealing ability

(2) Liquid bridge form/keep/store
  (c) Liquid bridge form/store
  (d) Sample volume adjust

(3) Tracer expel/withdrawal
  (e) Valve/tracer compatibility
  (f) Tracer expel
  (g) Tracer withdrawal

To reduce the test cases, test 3-e shall be performed at first and select the type of seal, On/Off valve seal or Cap seal.

Sample and tracer used in the BBM test are described below.

Sample: Silicone Oil 5cSt viscosity

Tracer: MX-3000NA (Soken-Kagaku Co.)
Ni/Au coated acrylic resin
30 micrometers diameter

2.5 BBM test results

Results of each test shown on section 2.4 are described below.

(a) Bubble contamination

When the pump (as a sample dispenser) is filled with sample, bubble must be eliminated to prevent bubble contamination to the liquid bridge. In this BBM test, sample filling has succeeded with no bubble. However, when the liquid bridge is formed after clean up of the cooling disk, bubble has appeared in it. Because the bubble contamination at that situation is almost impossible to prevent on this BBM, this issue (including the procedure of clean up) must be investigated using remodeled BBM in next phase.

(b) Sealing ability

This test has two aspects; one is the sealing for air to prevent bubble contamination, the other is sealing for the sample leak. Because the tube or fittings had not been tight enough for the sample leak, this issue should be investigated using future BBM utilizing the current sample cassette seal design. Airtightness could be tested on this type of BBM when the sample is filled by vacuum method in the next phase.

(c) Liquid bridge form/store

When the liquid bridge is formed, sample dispensing and cooling disk movement must be linked each other. As a result of this test, electrical control (valve, pump and

stepping motor for the cooling disk drive) has succeeded then 2.5 mm length liquid bridge has formed straightly in 30 seconds. Additionally, the 2.5 mm length liquid bridge has been kept over 18 minutes and 1.5 mm length liquid bridge could be kept horizontally.

(d) Sample volume adjust

Since the MIDM has a narrow view window, sample volume shall be adjustable accurately. The variable volume pump that installed in the BBM has a minimum dispense value as 0.5 mm^3 per pulse. When the pump sent/stored a pulse of sample, surface of the shortest liquid bridge (1.5 mm length; Figure 2.5-1) moved significantly, but it's small enough for the MIDM view because the view located around the edge of the heating disk.

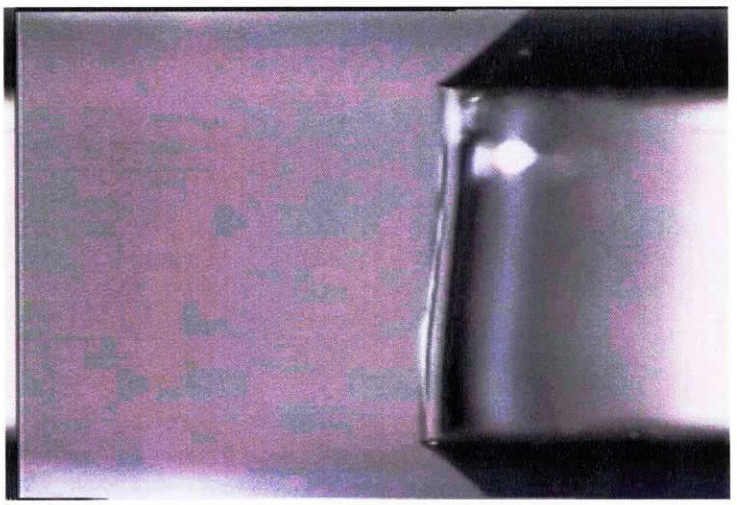


Figure 2.5-1 Surface of the liquid bridge (1.5 mm length)

(e) Valve/tracer compatibility

This test confirms compatibility between the micro-valve and the tracer. Since tracer choking is possible on the On/Off valve seal type BBM, tracer passage test through the micro-valve shall be conducted. As a result of this test, tracer chokes in the micro-valve. Therefore, the other tests were performed only for the Cap-seal type BBM.

(f) Tracer expel

Despite it's settled in a while, 30 microns or smaller tracer could be expelled enough, under 2.5 mm length formation in 30 seconds. 10 microns or 20 microns tracer had a good performance. Approximately half number of 30 microns tracer could not be sent out. At each case, the number of the tracer could not be counted.

(g) Tracer withdrawal

Because a settlement of the tracer, it was remained on the disk after the sample withdrawal as shown in Figure 2.5-2.

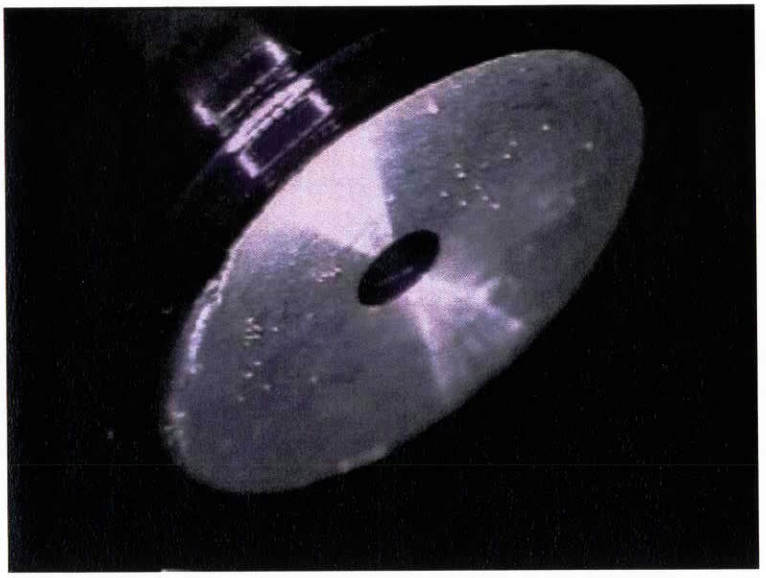


Figure 2.5-2 Tracers remain on the cooling disk

2.6 Observation system design

Based on the current cell design, such as envelop, shape or arrangements of optical system, the observation system had designed as shown below. Commonization of the observation system on variable diameter of the liquid bridge will reduce the development cost of the test cell significantly.

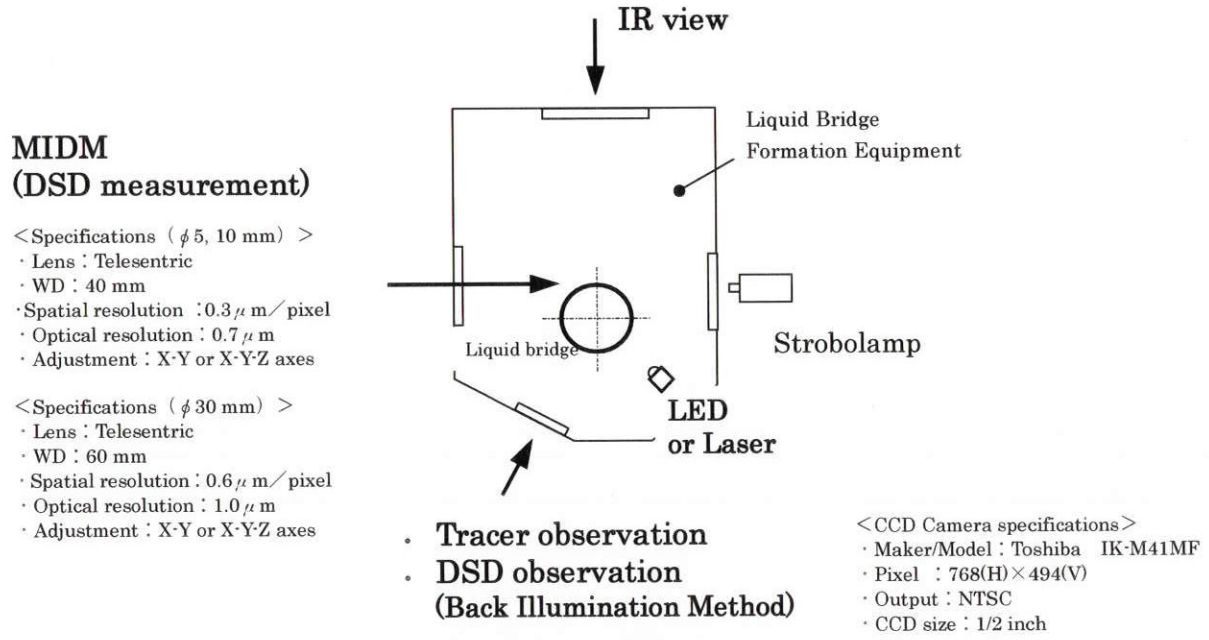


Figure 2.6-1 Outline of observation system design