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In-situ cleaning of the primary mirror of Subaru telescope

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ABSTRACT

The factors degrading optical performance of the telescope optics are the deterioration of the reflecting coating itself on the surface, and the accumulation of the contamination on the mirror surface. We consider that fine cinders at the Mauna Kea summit are blown into the enclosure by wind and get stuck on the optical elements, particularly on the primary mirror as it has large area and it will be looking up the sky for long hours during its operation. Contamination on the primary mirror surface decreases its reflectivity and increases its emissivity and scattering. These will affect the observational efficiency of the Subaru telescope, for it will be used in the wide range of the wavelength. Not only the decrease in the reflectivity but also the increase in the emissivity are of major concern in the infrared region. In order to prevent the accumulation of the contaminant particles, which cleaning technique could be applicable for the large telescope optics ? Several cleaning methods to replace freon washing are devised to clean silicon wafer in its production process in the semiconductor industries. We adopted basic concept from such techniques and made experiments in the hope of using for the preventive maintenance of the telescope mirrors.

Keywords: in-situ cleaning, dry ice cleaning, contamination, scattering, large optics, reflectance, emissivity, 8-m optical/infrared telescope, Subaru Telescope, blowing pressure

1. INTRODUCTION

Dry ice (solid carbon dioxide) in-situ cleaning method is one of the candidates for cleaning large area, and we have conducted experiments to understand why this method is better than others such as dry air blowing technique or water washing. The result clearly confirmed the better performance of the dry ice cleaning. We have further investigated to refine the parameters of this method, such as the shape of the nozzle, distance between the mirror, blowing time, and direction with respect to the mirror. We will report the results and implication of these experiments that lead to the design concept of the dry ice in-situ cleaning system for Subaru Telescope.

2. EXPERIMENT

2-1. SET-UP OF THE EXPERIMENT

Basic set-up of the experiment includes the sample mirrors that represent the telescope mirror and the dust box that simulates the accelerated contamination environment of the telescope in the enclosure. We used aluminized glass samples of 8 cm by 8 cm (3.5 inch by 3.5 inch) size, and 1.3 mm thick. They were placed on a material with big thermal capacitance, such as a thick glass or an aluminum plate. In order to simulate the dusty contamination at the summit, we used a dust box

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of 70 x 40 x 50 cm size for blowing cinders onto the sample mirrors (Figure 1: photograph of the dust box). All the samples except the ones labeled clean references were made in this dust box. To keep track of the cleaning effect, we use a portable scatterometer named micro scan made by TMA. It measures reflected light at 670 nm toward three directions and gives the Bidirectional Reflective Distribution Factor (BRDF, Stover, J., C., 1990) and the specular reflectance of the sample mirrors. Picture of the scatterometer set-up is shown in Figure 2. Separation between the sample and the scatterometer was fixed to 2 mm by the special holding arms to avoid direct contact on the mirror surface. We measured 10 points in each samples.

The important characteristics for the cleaning agent are the purity of the agent gas/liquid itself and the shape of the nozzle where the agent goes out into the open air. We show narrow nozzle for dry ice and air nozzle on Figure 3. The nozzle characteristics are summarized in Table 1. The conversion efficiency of narrow nozzle from liquid carbon dioxide to dry ice is 17%.

2-2. POSSIBLE CLEANING TECHNIQUES

Candidates of cleaning techniques are dry ice blowing, dry air or nitrogen gas blowing, pure water washing, or stripping off of adhesive material. Carbon dioxide blowing (liquid in original form) actually produces both cold solid and gas form of carbon dioxide. First, we made comparison between dry ice blowing versus dry air blowing. Result of this experiment is shown in the graphs 1, 2, and 3. Reflectance and BRDF data are normalized to the new sample mirror. Number is the cycles repeated and number 0 is the new sample mirror in each graph.

Graph 1 shows dirty reference, that is to say, a sample never cleaned. As the cycle number increases, the reflectance decreases and the scattering increases monotonously. In the end, this sample was dry ice cleaned and the point dramatically returned to the starting point. After cycle number of 8, a wave-like pattern started to appear on the glass, like the wind patterns on the sand. In cycles 18, 19, and 20, we made adjustment on these mirrors to avoid interference from large amount of big size dust. In the operation of the telescope which sits higher up from the ground, the large dust grains will not reach the primary mirror. By turning the sample mirrors upside down, the grains larger than about 50 micrometers were removed.

Graph 2 shows the case of air cleaning. The result is similar to the non cleaning case. BRDF value is smaller than the non cleaning case. In the end, this mirror is dry ice cleaned.

Graph 3 shows the case of dry ice cleaning which demonstrates the efficiency of maintaining the surface in good condition. There is no obvious correlation between the scattering values and reflectance values in this level.

Figures 4 to 8 visualizes the effect of air cleaning and dry ice cleaning. Figures 4 and 5 are pictures of the samples illuminated from their back. A lot of pin holes are seen in the air cleaned sample. This implies that the aluminum coating is damaged by this cleaning method. Figures 6, 7, and 8 are pictures of sample mirror surfaces illuminated from their front. Figure 6 shows dirty reference, then air cleaned (Figure 7), and finally dry ice cleaned (Figure 8). From the picture, air cleaning method seem to fail removing the dust smaller than about 10 micrometers.

Next, we compared dry ice technique with other cleaning methods; water washing and adhesive material. Narrow nozzle was used for dry ice cleaning process. For the water wash, we used water at room temperature. Purity of the water is about 0.07 micro siemens /cm using ion-exchange resin filter. After the sample mirror is dried, water mark appeared on its surface and pin holes developed later. The water cleaning is not enough to clean the surface as you see in Figure 9 that there are small dust grains stuck inside the water marks. The dry ice was able to remove these contamination as seen in Figure 10.

The dry ice cleaning case can not remove greasy contamination such as fingerprint. To assist this kind of contamination, we tried another material. An adhesive material is painted over the fingerprints, water marks, and cinders on the dirty sample mirror. After the material dried and changed as film, we stripped that film from the sample. Stripping off of the adhesive material case can remove fingerprints, water marks, and cinders almost perfectly.

Experiments on different techniques are summarized in the graph 4. The label Gravity shows the data when the dirty sample was turned upside down without any shaking, OPC shows the data for adhesive material whose product name is Opti-clean polymer, W(P) is the wash with pressurized water, W(F) is the wash with floating water, and dry ice shows dry ice cleaning applied after floating water wash. The bold line bar is the simple dry ice cleaning case.

3. DETAILED EXPERIMENT OF DRY ICE CLEANING TECHNIQUE

3-1. DRY ICE PARAMETERS

Important parameters that we have to determine from experiments for designing the telescope cleaning machine, are the shape of nozzle, blowing distance, and blowing time. It is important to keep an eye on the side effect that might appear that affect long-term performance of the telescope optics. We also measured the blowing speed, visualized the stream line, and estimated efficiency of the conversion efficiency from liquid to dry ice, to understand the characteristics in this cleaning method.

We investigated the relation between cleaning efficiency and blowing time by using wide and narrow nozzles. The blowing distance between the mirror and the nozzle and the direction of the nozzle with respect to the mirror are set as the same for both the wide and narrow nozzles. Number of sample mirrors for wide and narrow nozzles were 3 pieces and 2 pieces, respectively.

3-1-1. BLOWING TIME

Graphs 5 and 6 show dry ice cleaning by narrow nozzle case. Graph 5 shows the reflectance and graph 6 shows BRDF. Both reflectance values and scattering values (BRDFs) stay almost constant even the blowing time is more than 3 seconds. Blowing with narrow nozzle can return the sample mirror to the new mirror condition, with the blowing time shorter than 3 seconds.

Graphs 7 and 8 show dry ice cleaning by wide nozzle case. Graph 7 is the reflectance, graph 8 is BRDF with dry ice cleaning by widely open nozzle. Reflectance values and scattering values vary as the blowing time. Even though the blowing time was extended over 10 seconds, the reflectance did not increase nor the scattering decrease. Wide nozzle is not effective enough to reproduce the new surface condition.

3-1-2. DISTANCE

Table 2 is the relation between the cleaning efficiency and the blowing distance. Narrow nozzle case can return the mirror surface to the fresh mirror condition even when blowing distance was as large as 120 cm. Based on this test, the narrow nozzle is used for dry ice cleaning onwards and also in the comparison of this method with other cleaning techniques we reported above.

3-1-3. SIDE EFFECTS

We monitored not only the efficiency of the cleaning but also the negative side effect, while comparing various cleaning techniques. There appeared what we call polishing effect and honing effect.

Polishing effect is the improvement of reflectance and scattering characteristics for the fresh coating. When the dry ice cleaning is applied to the fresh mirrors, they often show increase in the reflectance and decrease in the scattering over the new mirror. Table 3 shows this effect when the dry ice is blown to the seven of new samples aluminized in less than one month. Table 4 is cleaning efficiency after 10 cycle times. We repeated dusting and cleaning on 4 sample mirrors in this case, when blowing time was 3 seconds, and blowing distance was 90 cm. It is confirmed that cleaning efficiency is maintained and no deterioration is found in the coating. The dry air blown samples show scratches on the surface, that is, the honing effect. Aluminized mirror cleaned by dry ice by more than 20 times did not show such a negative effect.

4. CONCLUSION

The experiment is summarized as follows and basic plan to install for the Subaru Telescope is given.

1. For practically possible application onto a large optics exposed to the outside air, dry ice cleaning is more efficient than other cleaning methods such as air blowing or water washing.

2. This experiment shows that the dry ice blowing time requires 3 seconds with blowing pressure on the mirror surface at 0.2 gf/cm^2 (0.0028 psi) to remove the fine cinders.
3. The aluminized mirror cleaned by dry ice 20 times did not show any negative effect seen in other methods.
4. It would be practical and effective to apply dry ice cleaning 2 times/month (converted from 20 times per year), if the re-aluminization cycle is 1 year.
5. We often experienced electro-static shock when touching samples after dry ice cleaning in the condition of humidity under about 40%.
6. Dry ice cleaning has polishing effect on a new coating, that is to seemingly improve reflectance and scattering.

4-1. AUTOMATIC CLEANING SYSTEM FOR SUBARU PRIMARY MIRROR

A conceptual drawing of automatic cleaning system is shown in figure 11.

Dry ice cleaning is proven to be practically effective in the in-situ cleaning of the large mirror, except for greasy contamination. At the start of the telescope maintenance operation, we are developing, with Mitsubishi Electric Corporation, an automatic dry ice cleaning system for the main mirror of Subaru telescope. Removal of the residual contamination is left to the future development of a UV laser cleaning, or other equally efficient alternative.

The basic structure of the dry ice cleaning system for 8.3m Primary Mirror of Subaru is as following:
1. 4 sweeping arms are installed under the center section of the telescope.
2. The moving point of the arms slide along the guide rail under the spider of the tertiary mirror.
3. Each arm has about two dozen nozzles, the distance between each nozzle and the primary mirror is 10 to 40 cm.
4. Blowing time is determined to be 3 seconds at blowing pressure onto the mirror at 0.2 gf/cm^2.
5. The shape of the nozzle conforms to the opening angle recommended from the experiment.
6. The number of nozzles per arm is determined from the blowing spray pattern, and the cleaning time is estimated from the conversion efficiency from liquid carbon dioxide to dry ice.

For the cleaning operation, the telescope is tipped to EL = 15 degrees, and the piping for the nozzles on each arm will be connected to the liquid carbon dioxide liquid container(s) at the telescope floor. High position arm starts to sweep and blow dry ice from the top to the center, the two middle position arms will follow sweeping from the center to the outside area, and the bottom position arm will sweep from the center to the bottom. The overall cleaning operation time is expected to be about 20 minutes. This machine will help weekly cleaning campaign to be easily accommodated to the telescope operation schedule.

5. ACKNOWLEDGEMENTS

We acknowledge the advice and supports from our colleagues in our observatory and from the scientists and engineers in other institutes or manufacturers. Special thanks is to the efforts by Mr. Shin-ya Kawahara and Mr. Takeji Ogasawara who started and finalized the design of the cleaning machine for Subaru Telescope.

6. REFERENCES

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Fig. 1 Dust box (about 70x40x50 cm)

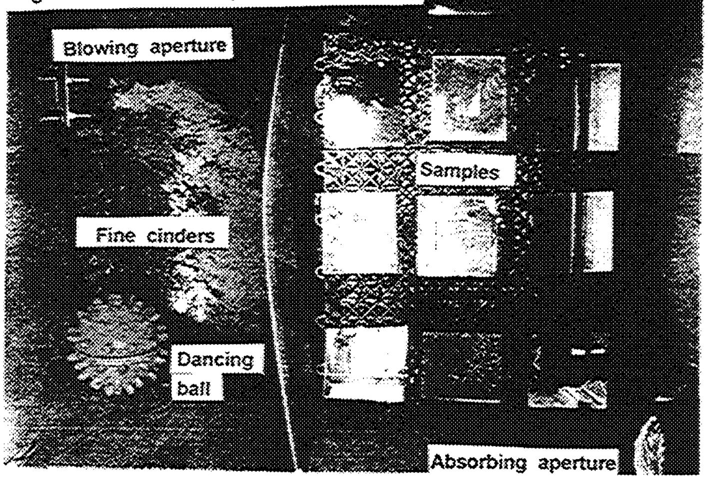
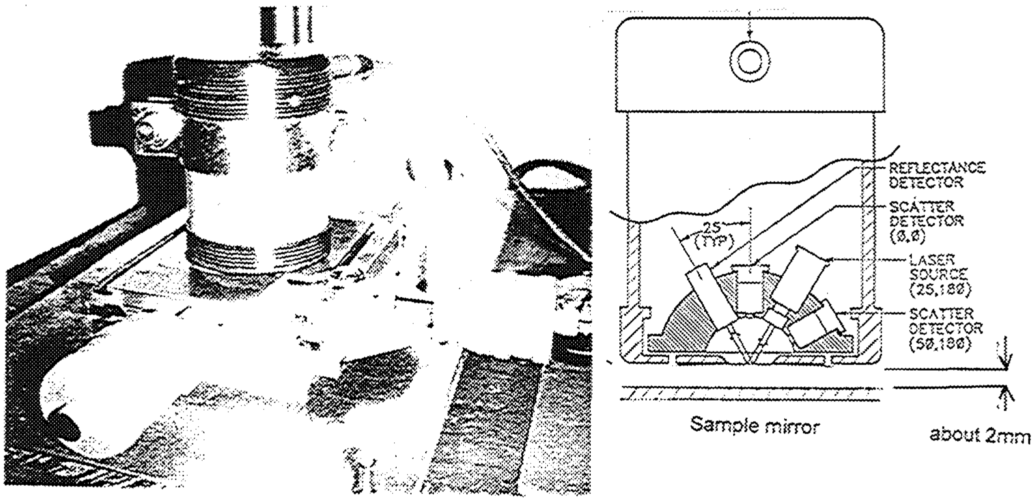


Fig. 2 The scatterometer set-up



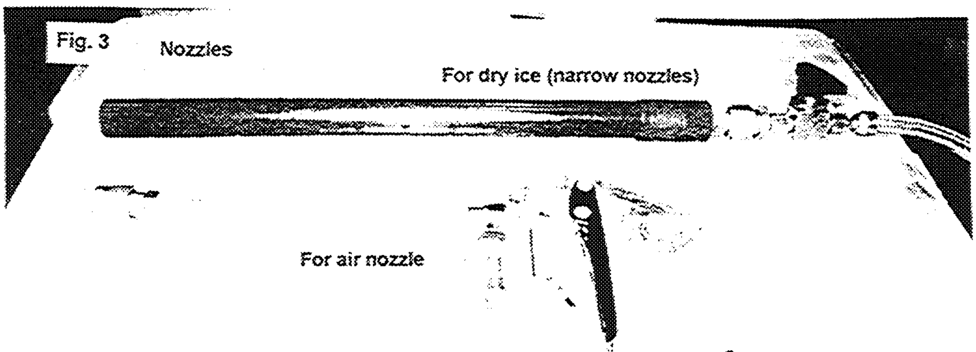


Fig. 3 Nozzles

Picture of sample mirror surface with light to surface

Fig. 6 Dirty

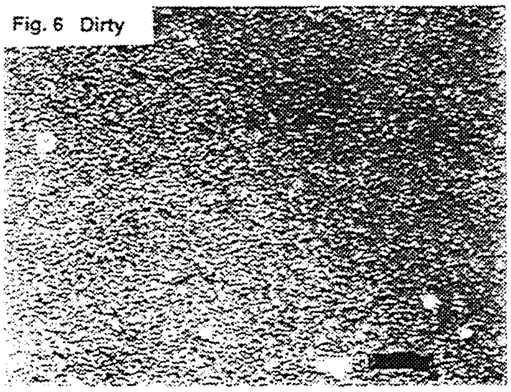


Fig. 7 After dry air cleaning dirty

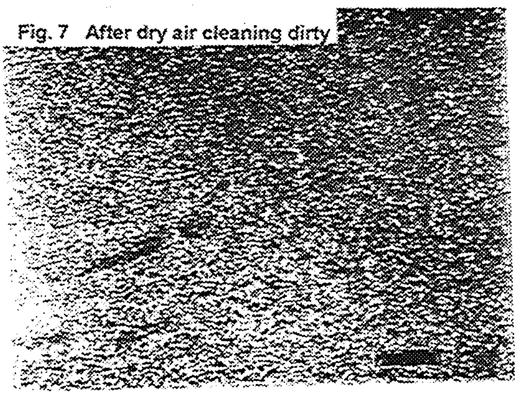
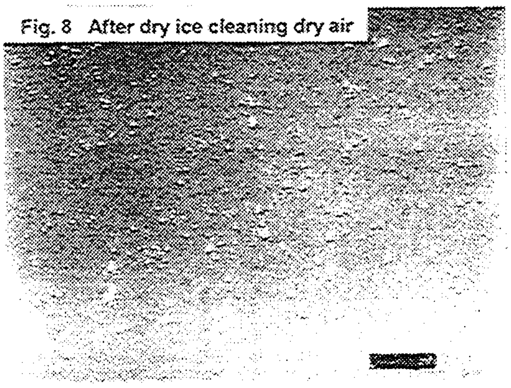
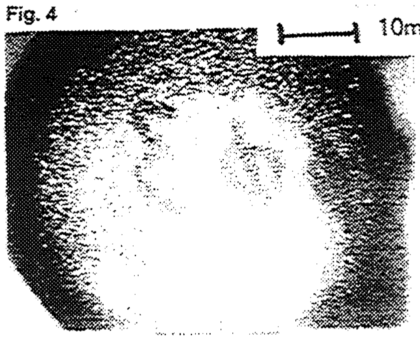


Fig. 8 After dry ice cleaning dry air



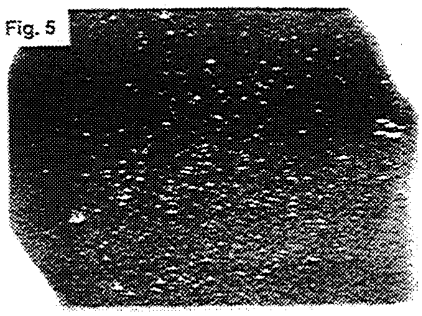
Applied light to surface
from back of sample

Fig. 4



Air cleaning case made a lot of pin holes

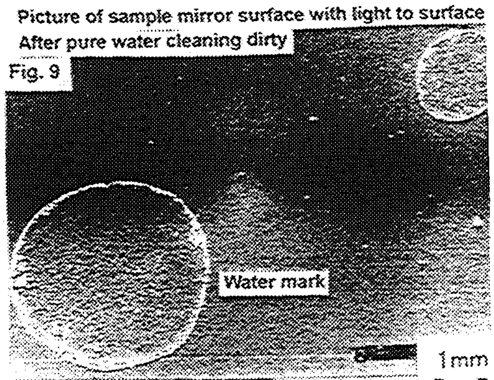
Fig. 5



Dry ice cleaning case

Picture of sample mirror surface with light to surface
After pure water cleaning dirty

Fig. 9



Pure water cleaning and dry ice cleaning

Fig. 10

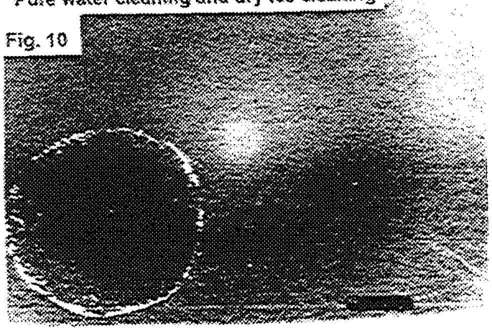


Table 1

Nozzle	Spread Angle (degree)	Pipe		Holes Number	Hole Diameter (mm)	Stream line
		Length (cm)	Inside Diameter (cm)			
Dry ice narrow	About 8	35	2	1	About 1	Straight
Dry ice wide	About 37	20	2	4	=<about 1	Spiral
Air nozzle		Non pipe		16	=<about 1	Straight

Table 2 The relation between cleaning efficiency and cleaning distance (1 cycle)

Nozzle	Distance(cm)	30	60	90	120
Narrow	Reflectance(R/Rn)	1.009	1.006	1.042	1.009
	(0,0) (B/Bn)	0.99	0.94	0.89	0.94
	(50,180) (B/Bn)	0.85	0.69	0.93	0.88
Wide	Reflectance(R/Rn)	1.000	0.998	0.993	0.988
	(0,0) (B/Bn)	1.00	1.84	4.64	4.86
	(50,180) (B/Bn)	1.49	5.09	17.41	17.93

Table 3 Dry ice blowing to new sample

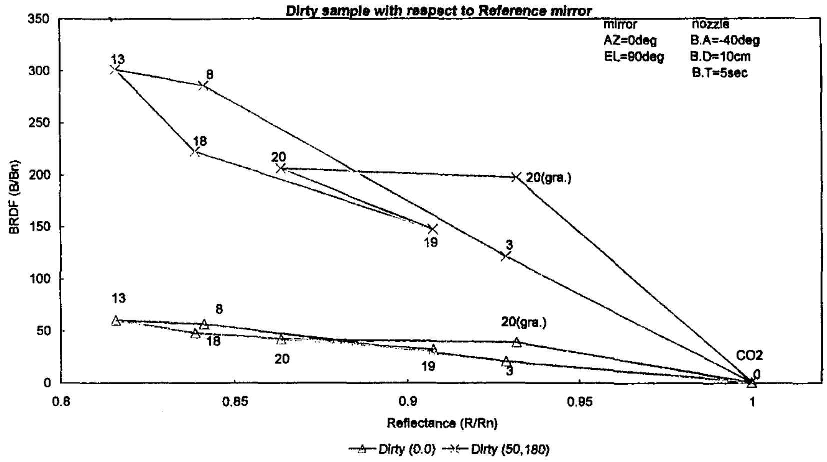
Sample No.	Reflectance (R/Rn)	(0,0) (B/Bn)	(50,180) (B/Bn)
Y12	1.002	0.84	0.71
Y13	0.999	0.88	0.63
Y14	1.000	0.84	0.56
YA3	1.004	0.65	0.36
Y9_2A	1.002	1.09	1.33
Y10_2	0.999	0.92	0.64
Y11_2	1.000	0.81	0.43
Mean	1.00	0.86	0.67
Std.	0.00	0.12	0.30

Table 4 Cleaning efficiency after 10 cycles

Sample No.	Reflectance (R/Rn)	(0,0) (B/Bn)	(50,180) (B/Bn)
Y12	1.001	0.92	0.51
Y13	1.004	0.99	0.66
Y14	1.005	0.99	0.54
YA3	1.008	0.76	0.39

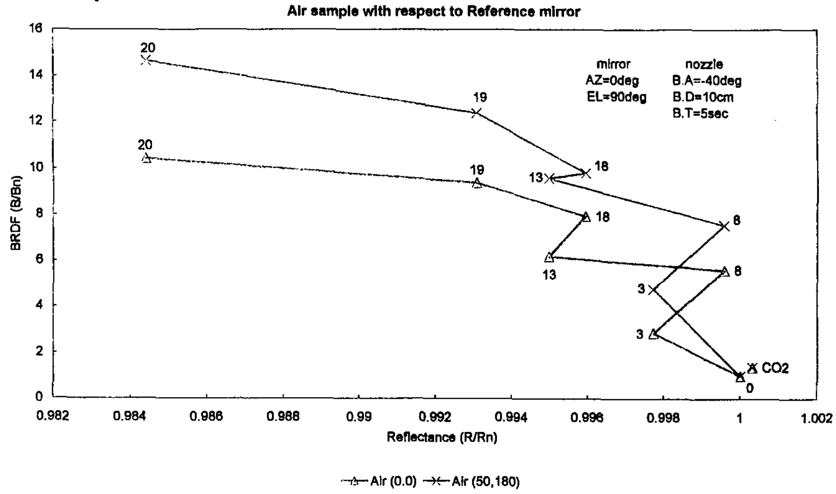
Graph 1 **The relation between Reflectance and BRDF**

Dirty sample with respect to Reference mirror



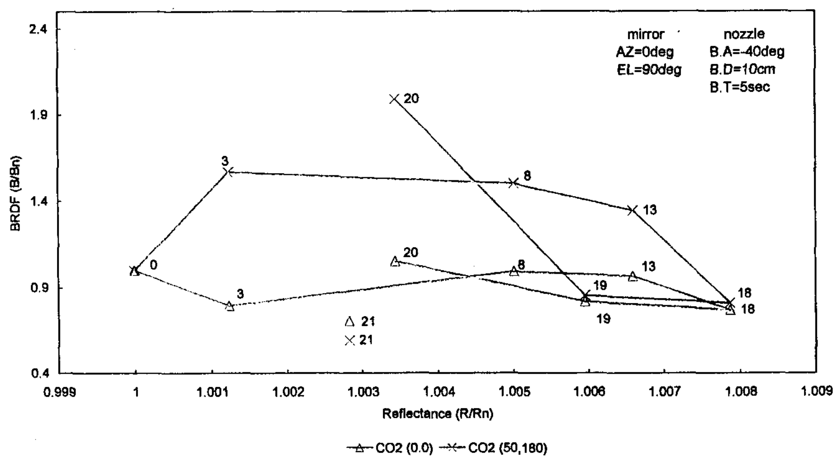
Graph 2 **The relation between Reflectance and BRDF**

Air sample with respect to Reference mirror



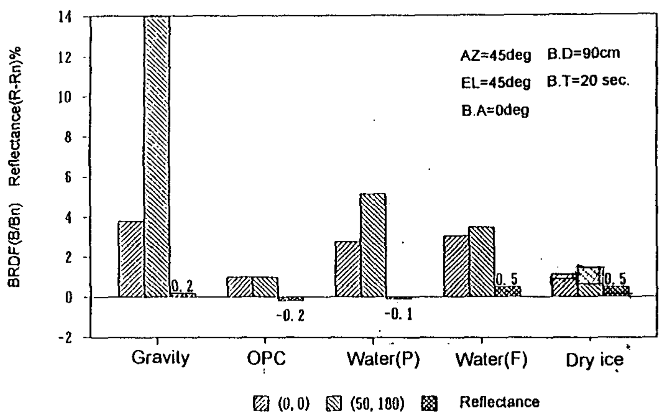
Graph 3 **The relation between Reflectance and BRDF**

Dry ice sample with respect to Reference mirror



Graph 4

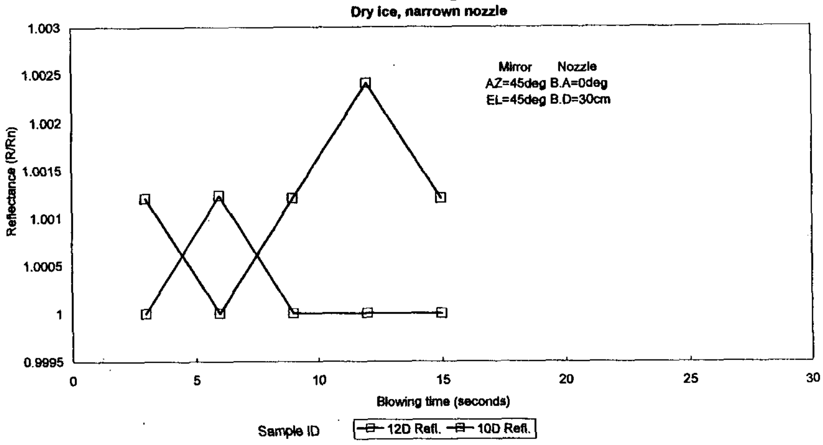
Compare of cleaning methods



Graph 5

The relation between Blowing time and Reflectance

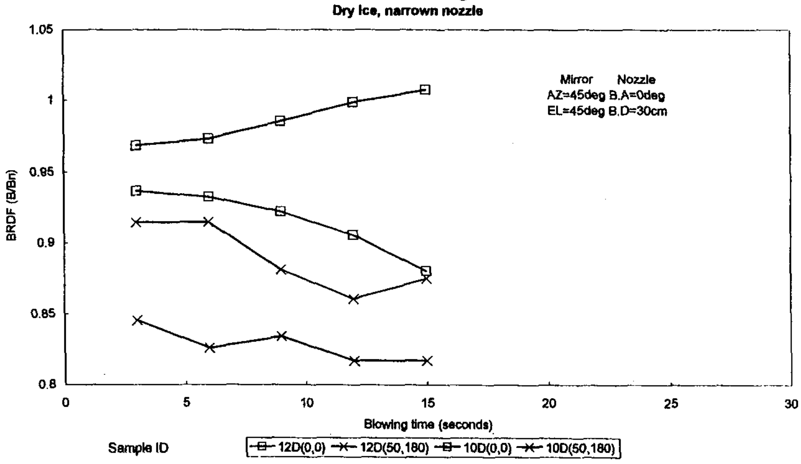
Dry ice, narrown nozzle



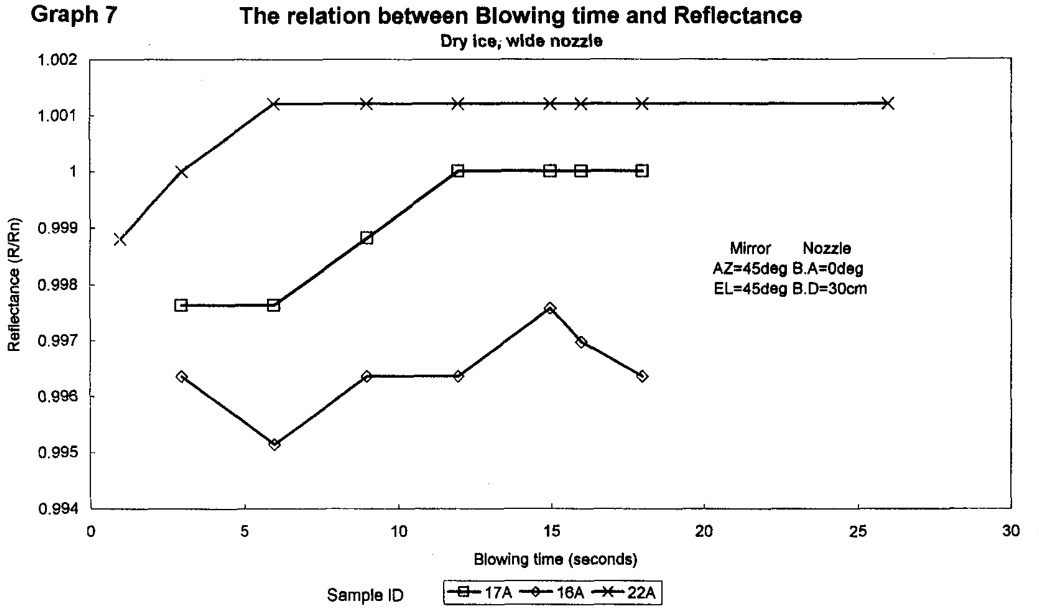
Graph 6

The relation between Blowing time and BRDF

Dry ice, narrown nozzle



Graph 7



Graph 8

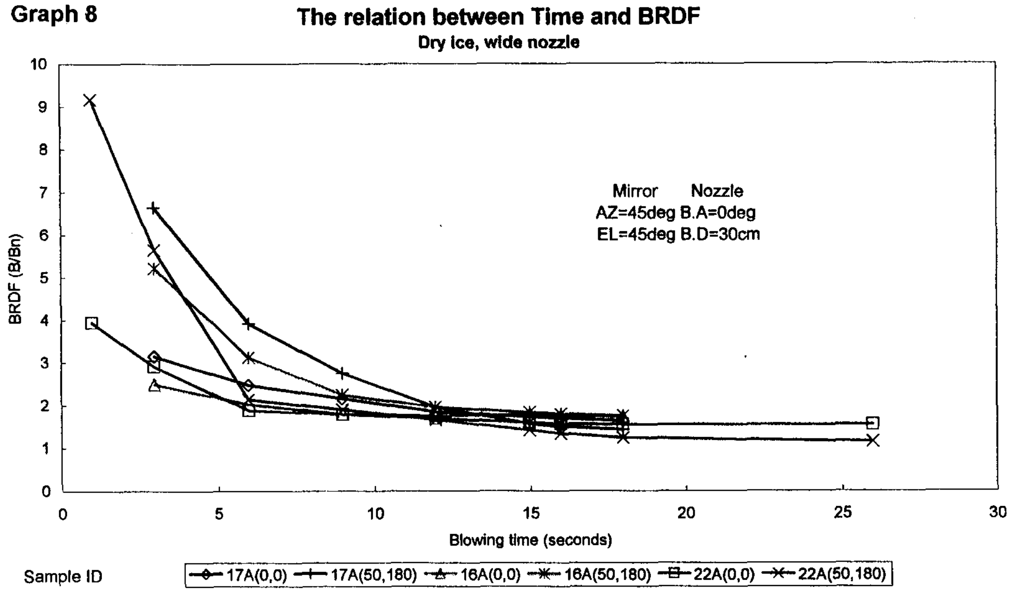
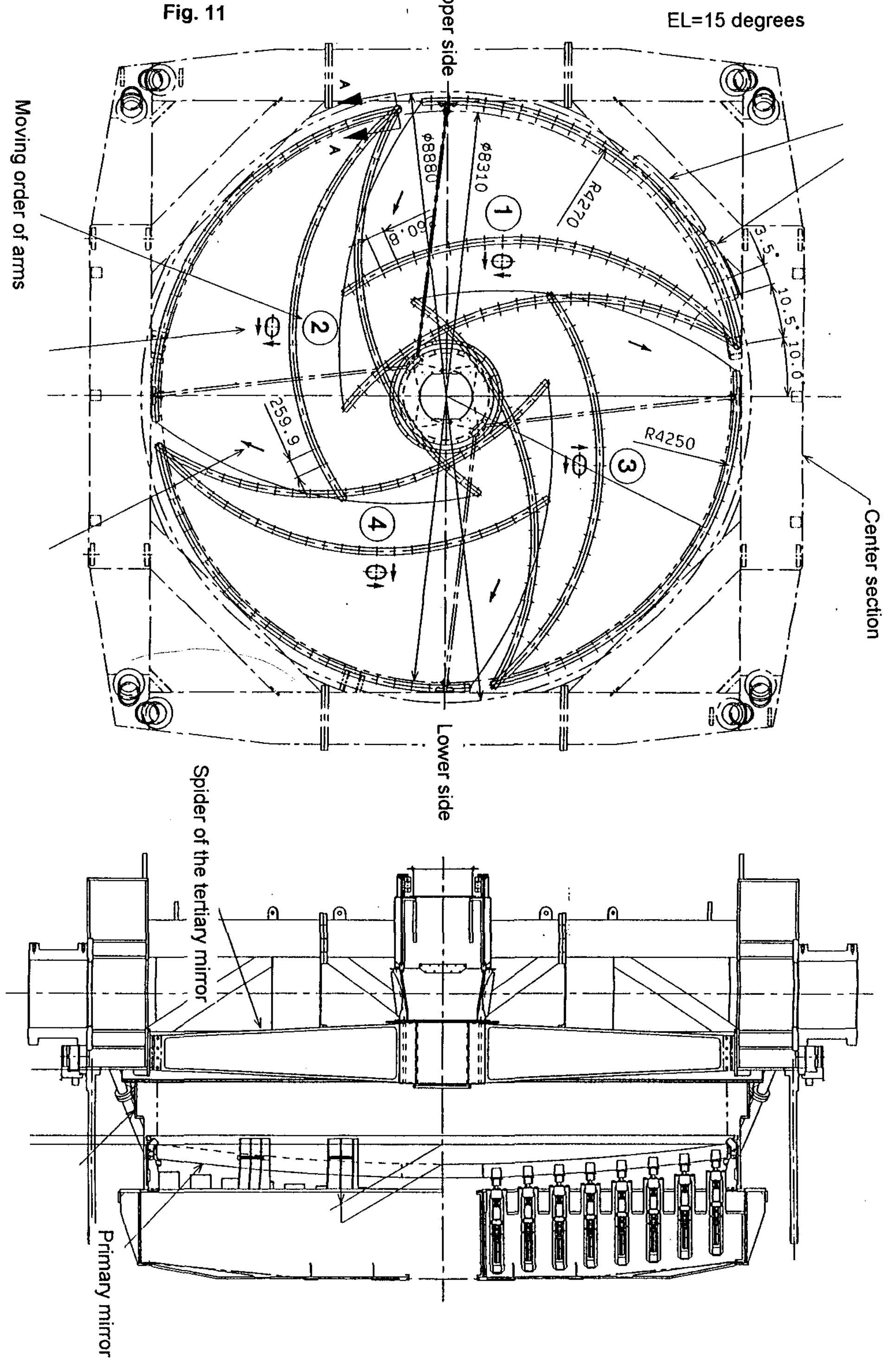


Fig. 11


EL=15 degrees
Upper side
Lower side
Moving order of arms
Center section
φ8880
φ8310
R4270
R4250
259.9
8.0
3.5°
10.5°
10.0
1
2
3
4
A
Spider of the tertiary mirror
Primary mirror