A New System for Automatically Registering and Exposing Solder Mask and Other Photopolymeric Materials Requiring High Energy Lamp Sources

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This paper is a continuation of the work presented at the HKPCA / IPC Conference held in Shenzhen China, on December 3, 2009. As an introduction, and to provide continuity, I will present some material from that paper.

LIGHT ENGINE DEVELOPMENT:
Historically most processes in the manufacture of PCB's have migrated from manual processing modes to full automation. Over the years the IPC Technology Roadmaps, as well as independent studies by such companies as PRISMARK Associates, have clearly demonstrated that the human interface causes more defects than any other source. Automation tends to eliminate this source of error.

One area that has resisted this trend up to this time is the area of Solder Mask imaging and other lengthy processes such as conformal coatings. There are at a number of reasons for the inability to automate these processes presently. I will use the SM process as an example of the problems faced with automation.

- The SM process comes toward the end of the PCB manufacturing sequence. As such, the product to be imaged has already accumulated a number of process deviations and these tend to be additive in nature. Thus there are large variations from panel to panel.

- Almost all present SM materials require high levels of energy to complete the imaging process. It is not uncommon to need anywhere from 350 mj. per sq. cm. to 600 mj. per sq. cm., to complete the exposure process. Even with lamps capable of providing 10KW output, anywhere from 30 to 60 seconds may be required for a single exposure.

- Extended exposure times tend to also result in an increase in thermal energy in the exposure envelope. The artwork normally used for exposure is a coating of either silver halide or Diazo chemistry on polyester film. The heat build up in the exposure envelope normally results in expansion of the polyester film, resulting in poor registration of the A/W to the substrate.

The present systems for the exposure of SM and other photopolymers requiring high energy all utilize variants of metal Halide lamps. These lamps typically have one or more peaks in the UV wavelength range, and it is these peaks that provide the energy for photopolymerization. A typical spectrum for such a lamp is provided below:

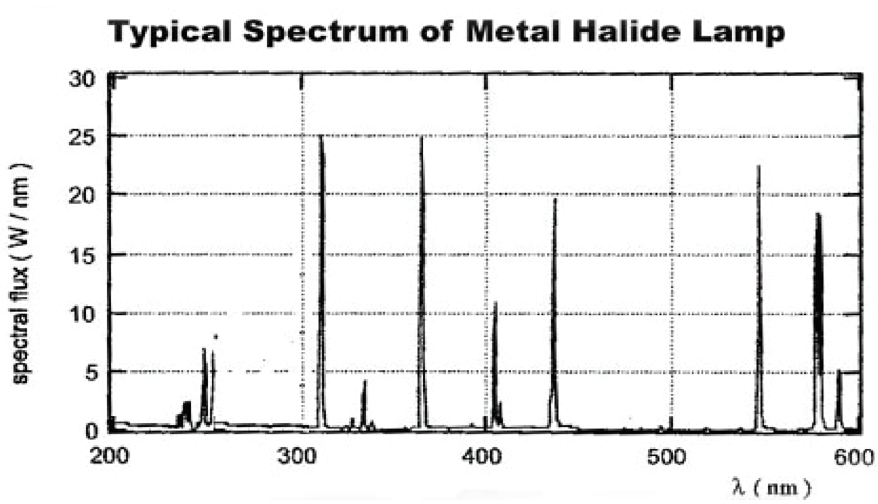


Figure 1

The critical peak shown in this spectrum is the one that falls at about 370 nm. The smaller peaks around 400 nm can also provide some degree of polymerization. It should be noted that these lamps also include a relatively high segment of energy in the IR range.

The new form of lamp has been designated by our development group as "Ultra High Energy Sources (UHES). Because of present patent considerations, the actual lamp specification will not be provided. However a typical output spectrum is shown next;

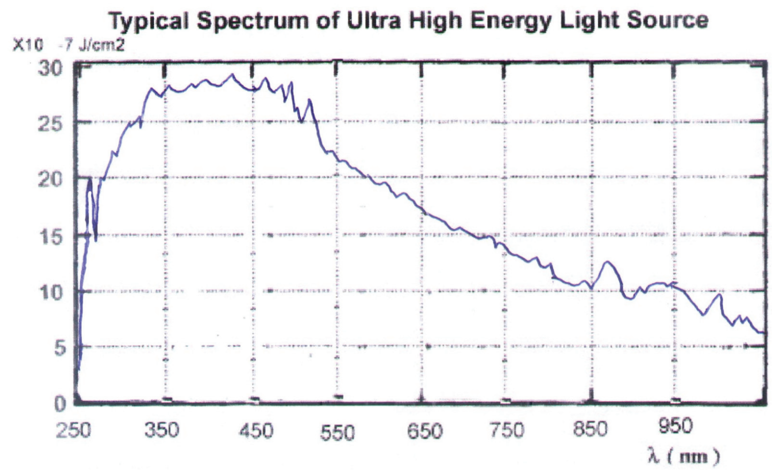


Figure 2.

It is important to note that the UV output, instead of being a few peaks, is diffused over a large band of light. However this UHES also has a large visible and IR output, and the resultant heat can cause problems of distortion of the artwork.

The solution has been the development of a "Modified Ultra High Energy Source" (MUHES). A spectrum using an IR filter is shown below.

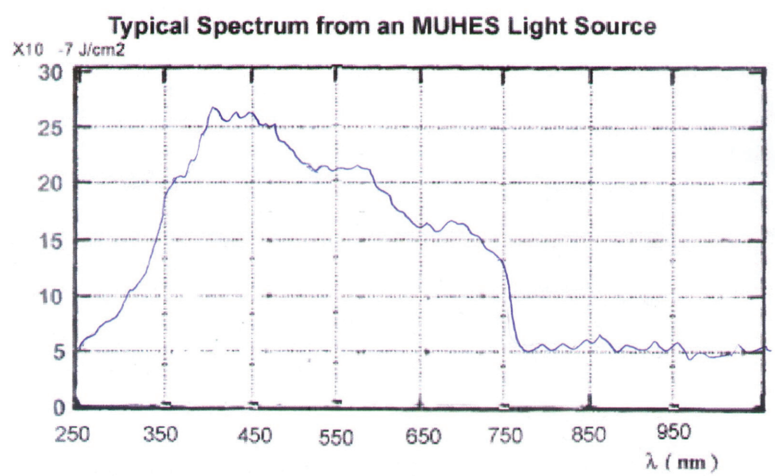
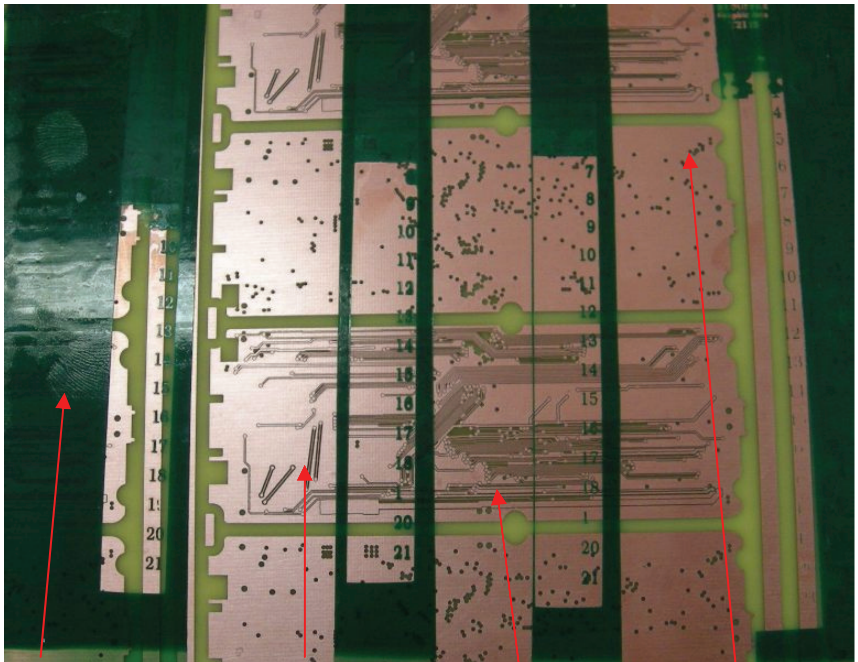


Figure 3

As can be seen in the above spectrum, the UV segment is still very rich, but a portion of the visible range, as well as the IR range, has been eliminated. Thus it was felt that this type of lamp would have promise for SM polymerization, and a series of initial tests were performed to verify this theory.

Results of the initial testing are shown in the following series of pictures. The first is a set of Stauffer 21 step tablets for periods of 1, 3, 5, and 7 seconds.



7 seconds 5 seconds 3 seconds 1 second exposure time.

Figure 4

A series of tests were then undertaken using a Stauffer resolution tablet and the results were most promising. The test panel is shown below and was coated using a draw bar to obtain a dry film thickness of about 0.002" SM material.

A second set of tests was run with different artwork to provide a set of lines and spaces.

Figure 5

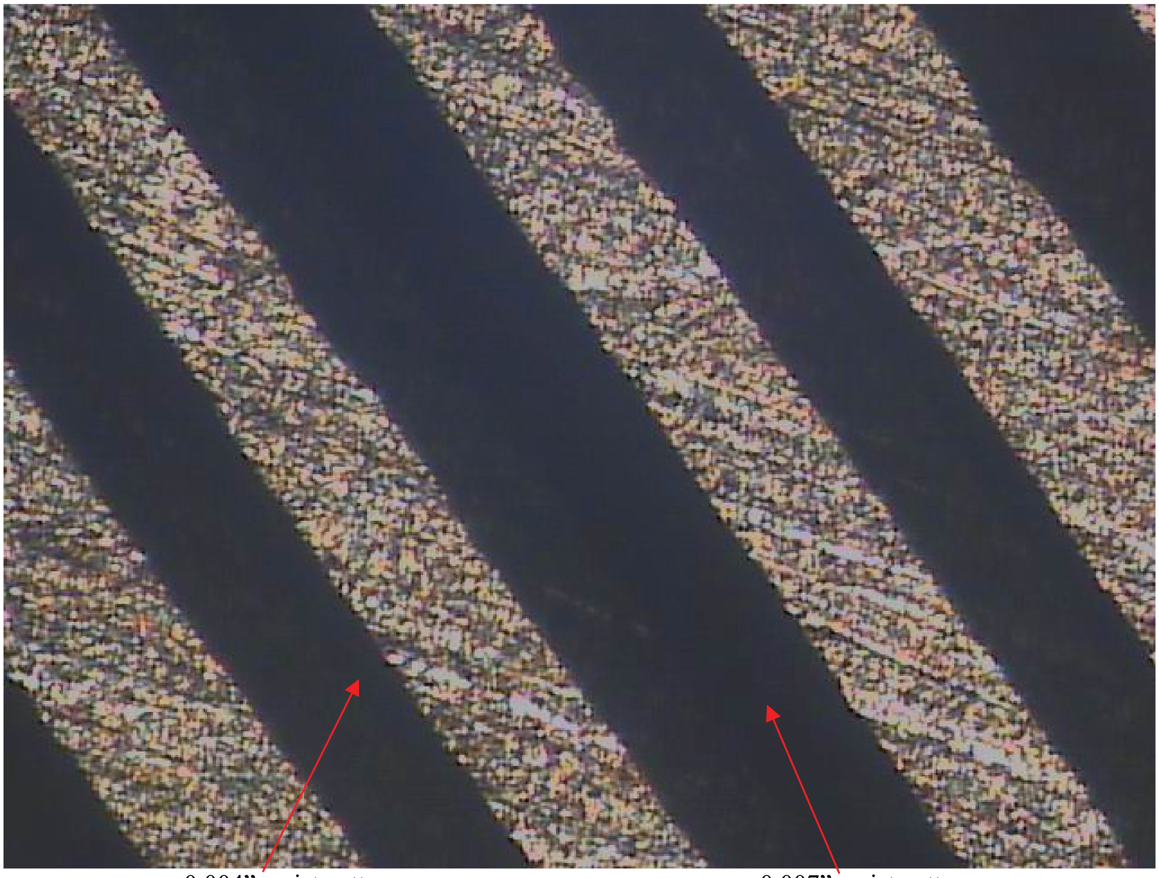
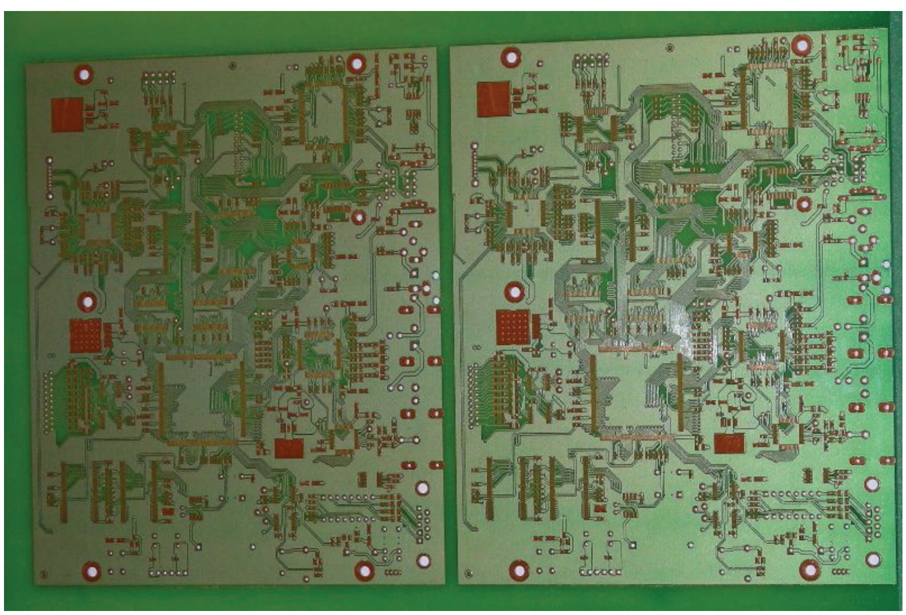


Figure 6

Finally a functional panel with circuit patterns and drilled holes was coated with resist by manual silk screening, and was developed for 45 seconds. This functional panel is shown in the next picture:



A separate test panel was sent for SEM analysis, and the resultant photomicrograph is shown below:

Figure 7

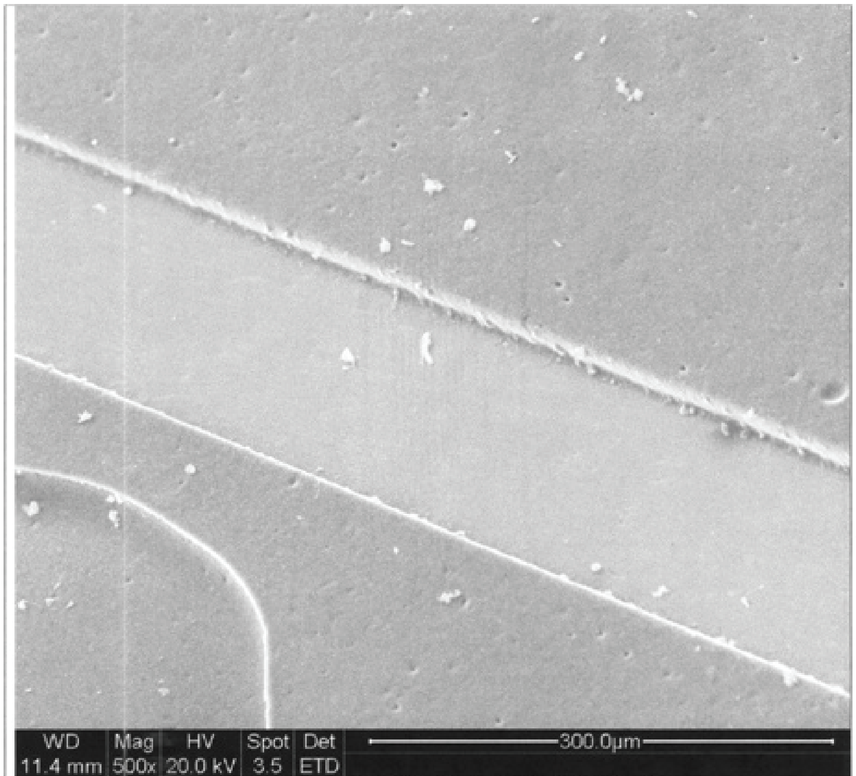


Fig. 7 SEM image of sample Unit #5 (500X)

SEM of a 100µ (0.004") opening in the SM material.

At this point, members of the development team were comfortable with the light engine, and proceeded forward with completion of the machine itself the machine itself.

MACHINE ACCESS FEATURES:

The first thing of importance was that we wanted the new unit to be easily accessible for maintenance. In many new pieces of equipment, accessibility is the last thing considered. With that in mind, initial planning was that every part of the system should be accessible within 10 minutes. The next picture shows the finished machine.

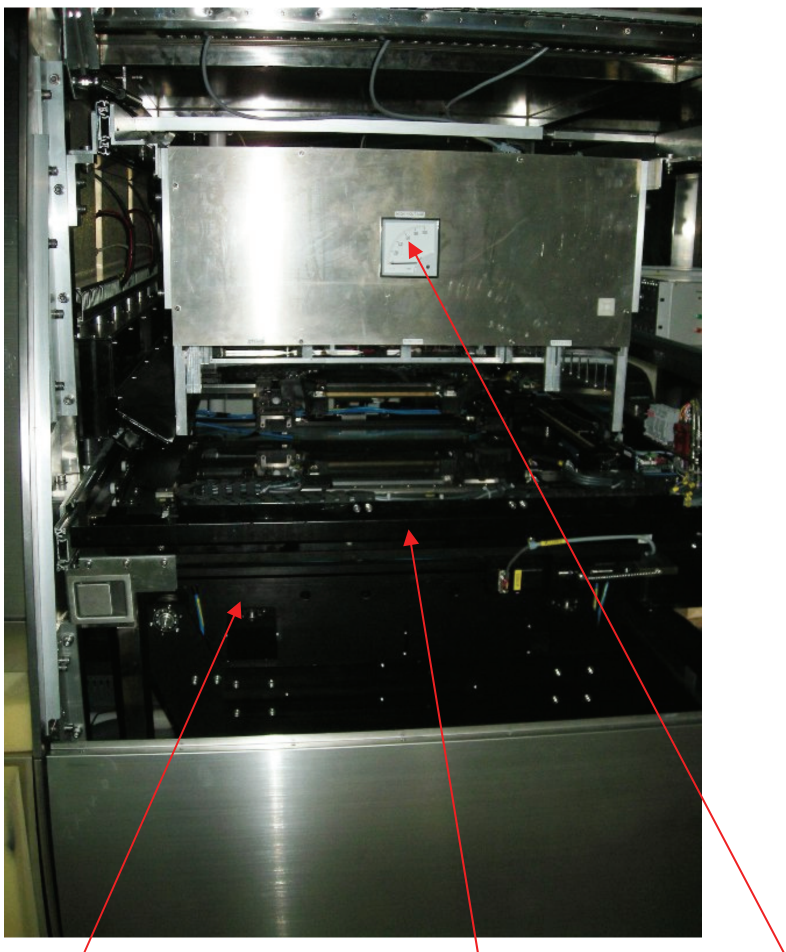
It has been fabricated with a stainless steel frame and stainless steel covers. Most other major segments of the machine are hard black anodize coated aluminum, ensuring no particulates within the machine itself. Cleaning of the exterior of the machine is either with a special stainless steel cleaner, or a standard spray cleaner.

There are two touch screens. The lower one is primarily for machine control, while the upper screen shows images from the 8 CCD cameras (4 per side). The initial goal is 4 two operator languages, Chinese and English. Additional languages will be added as needed.

The access covers for the exposure areas are hinged and supported by gas struts. The operator is therefore able lift these covers to access the exposure envelope to clean or replace artwork. All other covers are pin located lift off units. All sections have safety switches so that the system is shut down whenever access is made without a computer command that access is for service only. Even in that mode, power to the light engines is isolated, as the power levels for these are very high.

The unit exposes SM coated panels one side at a time. The decision for this was based on the problems with simultaneous 2 sided exposure for SM coated panels. As identified earlier these panels have an accumulation of process deviations from all earlier processes to account for at this step in the process. Single sided registration is much easier.

The machine is therefore split into 2 zones; side A and side B. Each process zone has 3 segments, the light engine, the alignment stage, and the panel platen. The panel platen is fixed within the zone, but the light engine and the alignment stage are each loaded onto slides, so they can be easily moved for machine or area access. The next picture shows zone B.

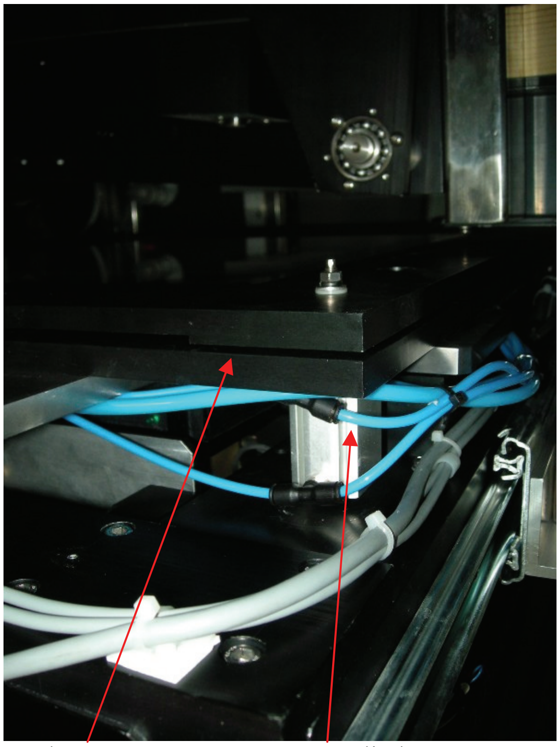


Platen base Alignment Stage Light Engine

The next picture shows one of these segments slid out for machine access.

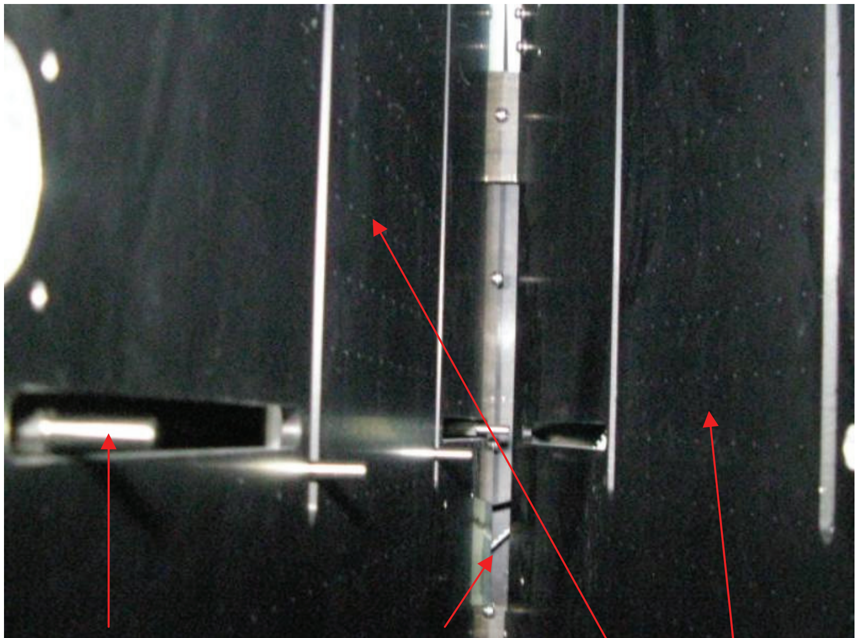
Alignment Stage slide mounts extended

Glass is replaced by extended the alignment stage as shown in the above picture. The operator or maintenance person then actives a 'glass replace' button on the touch screen, and 4 air actuated cylinders drop the glass tray. The person then removes 2 vacuum lines for film mounting, and slides the glass out of the tray. The reverse of this is used to insert a new glass.



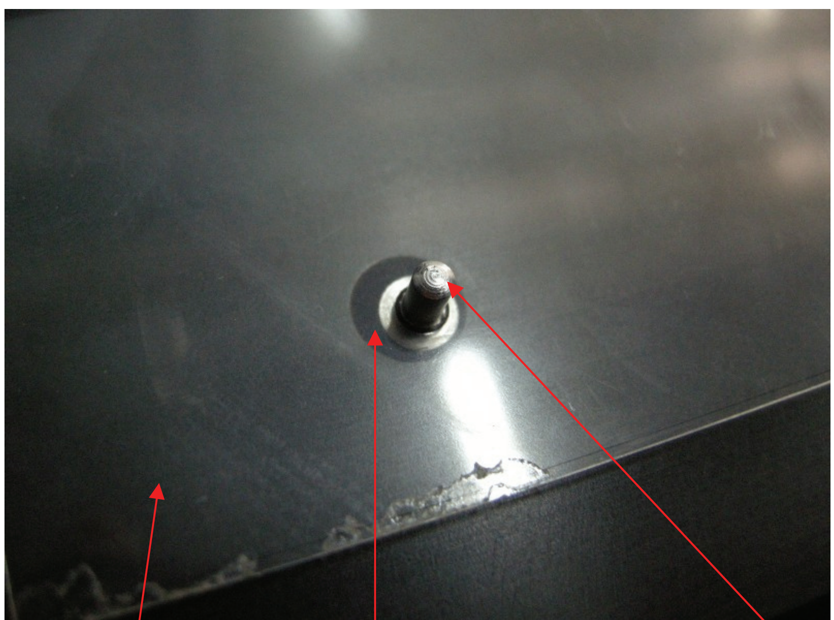
Glass tray Actuator cylinder

In any piece of equipment there is always the potential for a panel to be 'hung up', especially in the flipper that transports panels between side A and side B. The machine has been designed so that the cover can be easily opened, exposing the flipper mechanism. This is shown in the next picture:



Snubber pin Hinge Air float holes

Artwork change is extremely simple. When the film is plotted, two pads are placed on the mount edge of the film. These circles are then punched using a hand held punch.



Artwork film Punched hole in film Retractable pin

When a new job is planned, the operator merely uses the control screen to release the old film from the vacuum hold. The old film is then lifted off the platen. The operator then activates the retractable pin mount control, and air cylinders raise the mounting pins. The operator then places the film on the pins, and activates the film holding control, and then new film is mounted. Obviously this process is repeated for both side A and side B. A picture of the punched film is shown in the next picture.

SUBSTRATE TRANSPORTATION:
Other than the entry and exit conveyors that mate with the outside world, the panels ride through the machine on a bed of air. During transport, there is no contact between the substrate and the machine except in the exposure envelope. This includes the mechanism for turning the panel for second side exposure. The next picture shows the base platen for the exposure

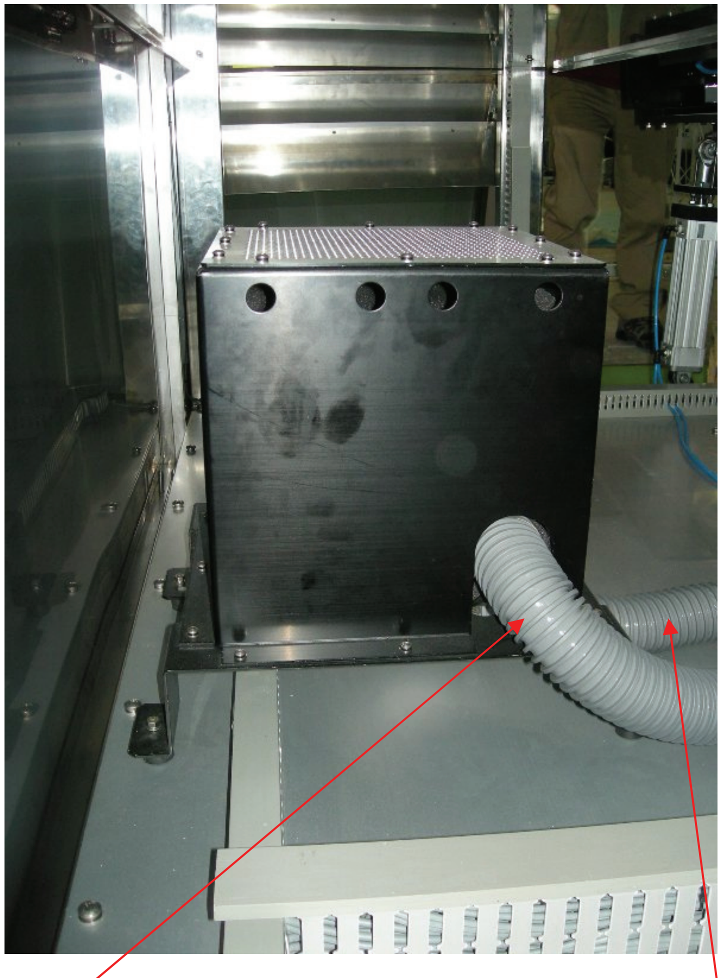
envelope. The small circular openings covering most of the surface are for the air ride mechanism, as well as for holding the substrate down during exposure. The slots in the platen are for the snubbing mechanisms that are used to align the panel within the exposure envelope. The groove around the periphery is for the expandable seal for vacuum contact with the glass. The 8 large circular openings will be defined later.

The next picture shows the platen in the machine. When panels are fed from either the entrance rollers or the flipper into the exposure area, the platen is tilted downwards at an angle of about 7 degrees. This allows the substrate to float into position on a bed of air. Once in the platen, and after the snubbers have correctly aligned the panel, vacuum is switched on to hold the panels in location. The platen is then tilted back to horizontal, and raised to the position for CCD camera alignment.

Platen at 7° tilt. Cylinders to move platen to parallel Drive to raise to expose level

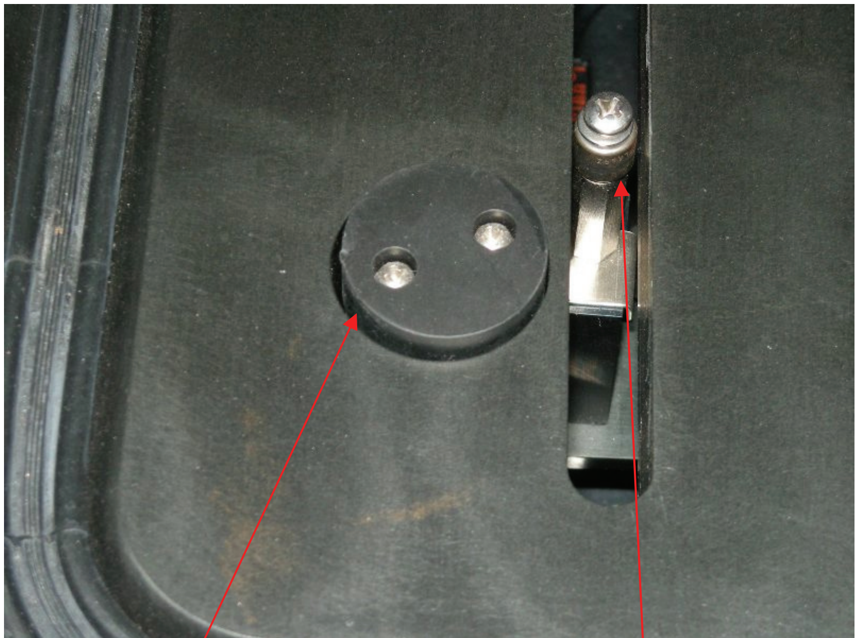
Obviously there was some concern with the cleanliness of facility air used for this purpose, and so the air for the float is provided by a unique motor that is both the supplier of air, as well as of vacuum. 3 such motors are in the machine.

In order to provide for the throughput required, the vacuum that is provided by these unique motors is an order of magnitude higher in cfm than normal vacuum pumps for exposure machines. We are very confident that the exposure envelope is sealed in less than 3 seconds. The machine also incorporates the use of high flow Mack type valves that allow the pumps to be switched immediately from vacuum to air pressure mode. The next picture shows one of the new design pumps:



Air flow outlet Vacuum inlet

It is quite normal when exposing panels for SM imaging to insert shims in the exposure frame. These shims serve to support the glass during the vacuum process, to eliminate bowing of the glass, as well as glass breakage. However the shims have a number of disadvantages: first they have to be changed for each panel size and thickness; and second, they tend to particulate allowing contaminants into the exposure envelope. One of the patented features of the new machine is that it has built in automatic shims that are set during the programming phase for a particular job, and that are adjustable in 10 micron increments. The shims can be driven by linear motors for extremely accurate location, or through gear reduction mechanisms for a less accurate requirement. The next picture shows one of these shims close up:

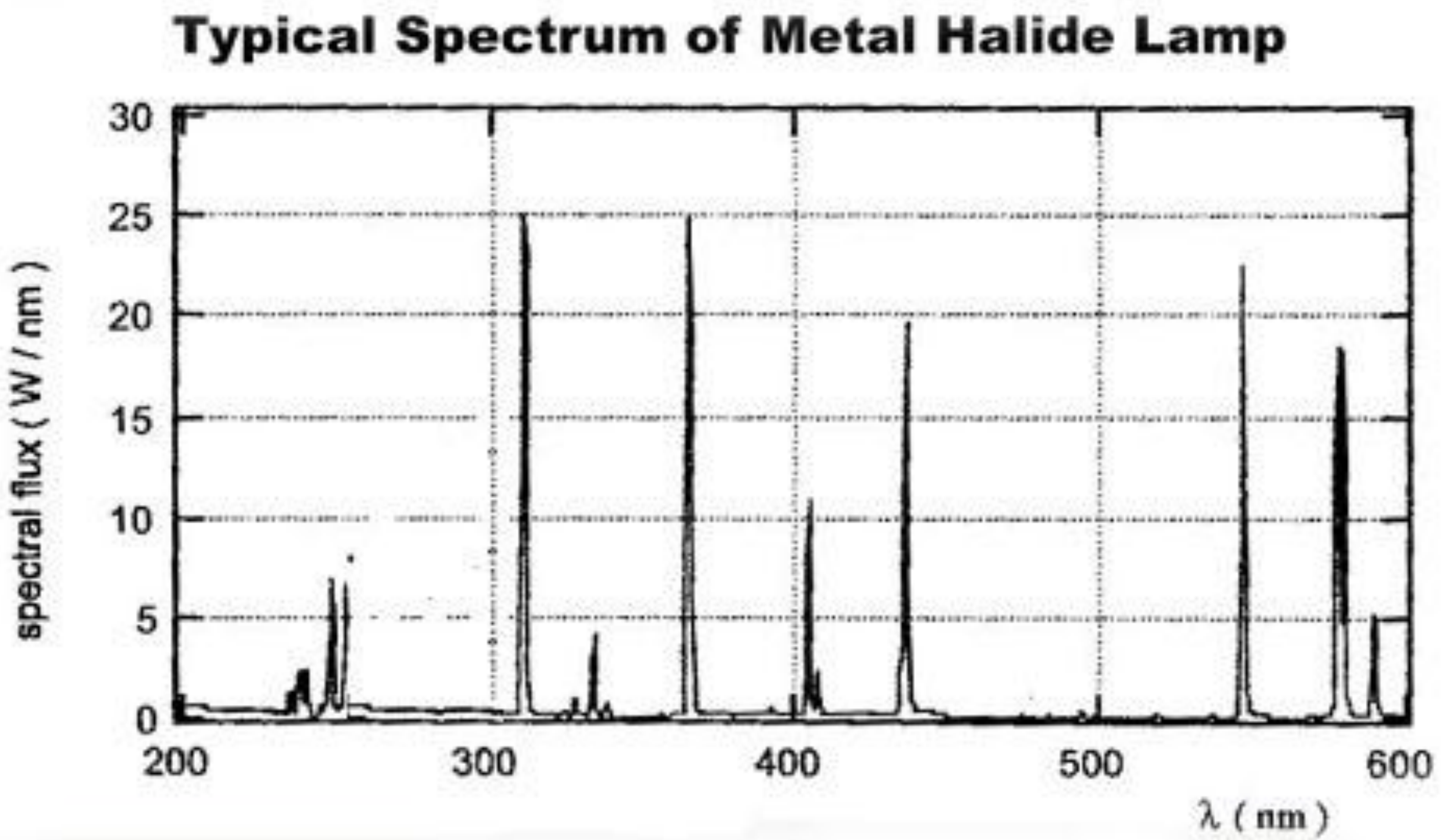


Shim, set for 0.062" material   local snubber post

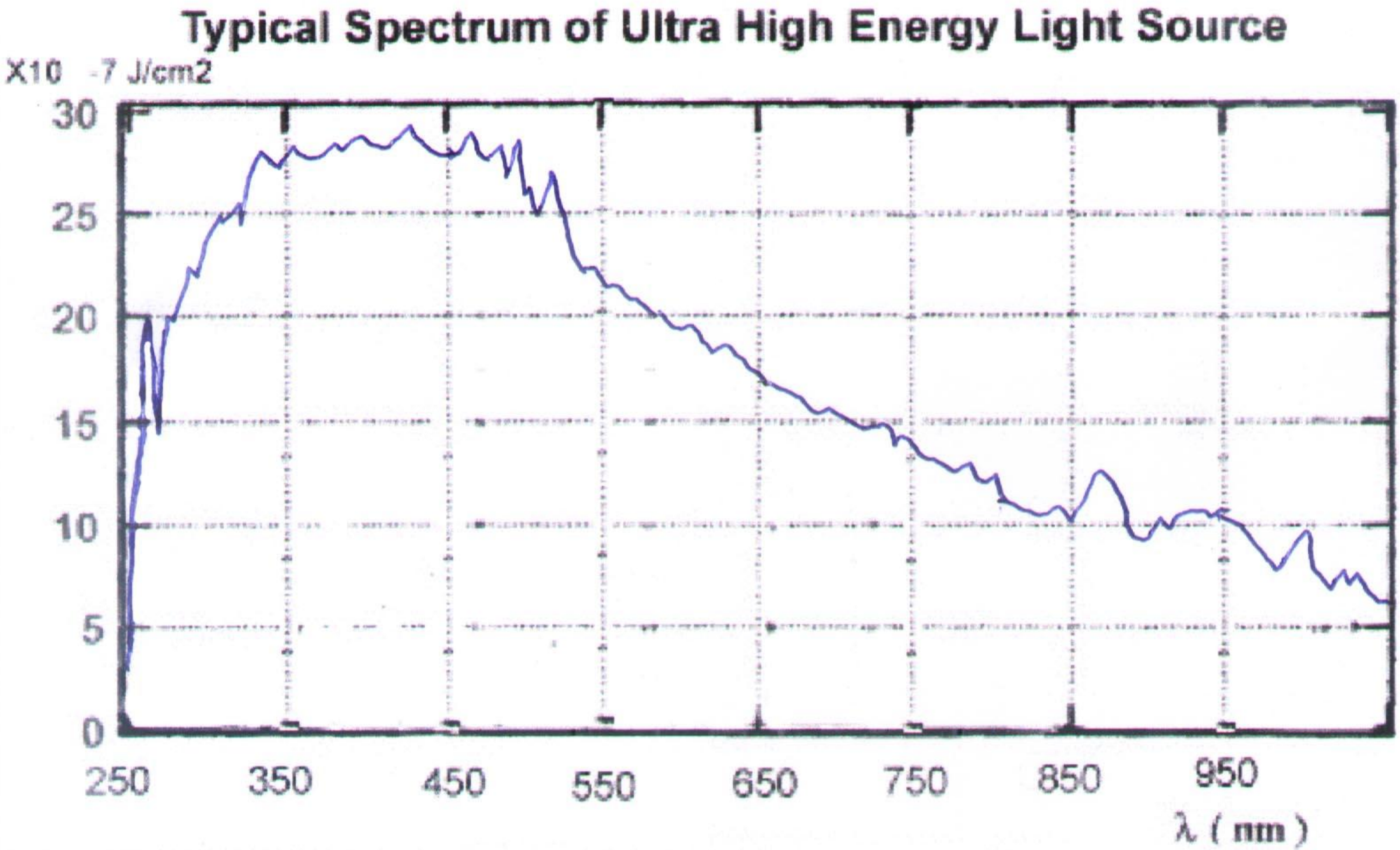
Initial testing of the system allows for a throughput of 120 panels per hour. The maximum panel size is 30" x 24". Due to camera movement restrictions, the minimum panel size is 14" x 14". While not completely defined at this point, it is expected that the machine can handle panel thicknesses from 0.010" to 0.200".

High Energy Exposure of Solder Mask Materials

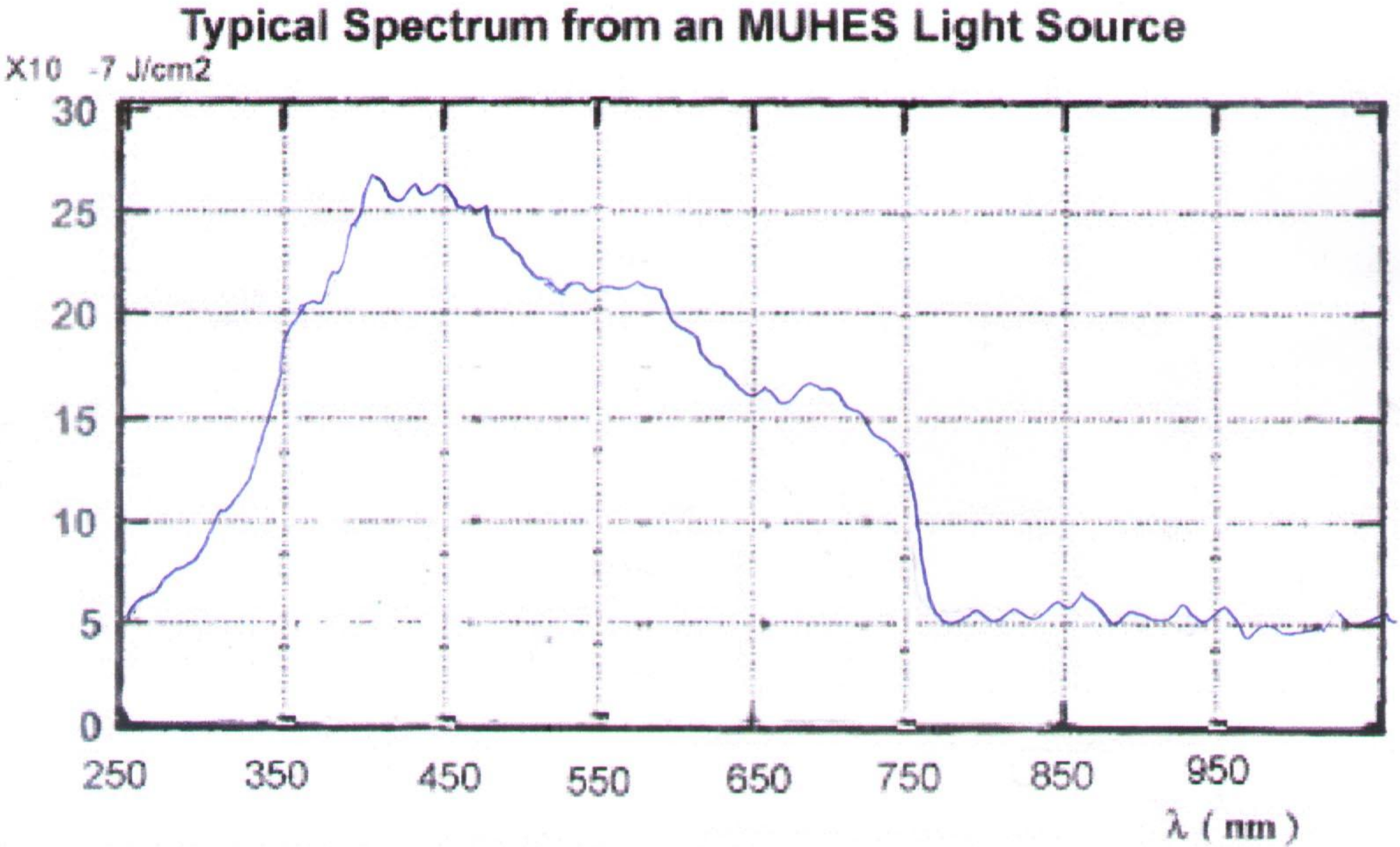
ORC Model X-Pose 120 Automated Exposure Machine.



Typical Spectrum of Metal Halide Lamp
spectral flux (W / nm)
30
25
20
15
10
5
0
200
300
400
500
600
λ (nm)



Typical Spectrum of Ultra High Energy Light Source
X10 -7 J/cm2
30
25
20
15
10
5
0
250
350
450
550
650
750
850
950
λ (nm)



Typical Spectrum from an MUHES Light Source
X10 -7 J/cm2
30
25
20
15
10
5
0
250
350
450
550
650
750
850
950
λ (nm)

Coating draw bar

First imaged panel

Light Engine Test Module

Radiometer readings

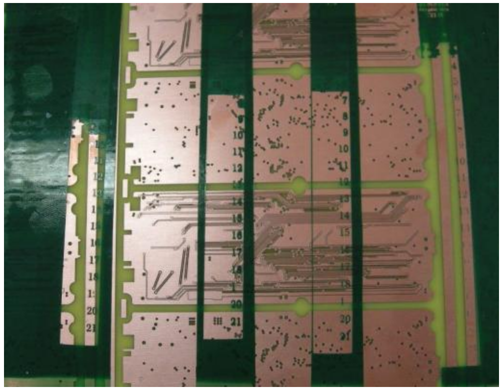
- Locations:

	» 1	2	3
1	1.26	1.244	1.238
2	1.268	1.272	1.256
3	1.275	1.164	1.275
4	1.283	1.265	1.267
5	1.263	1.273	1.230

Stauffer 21 step values

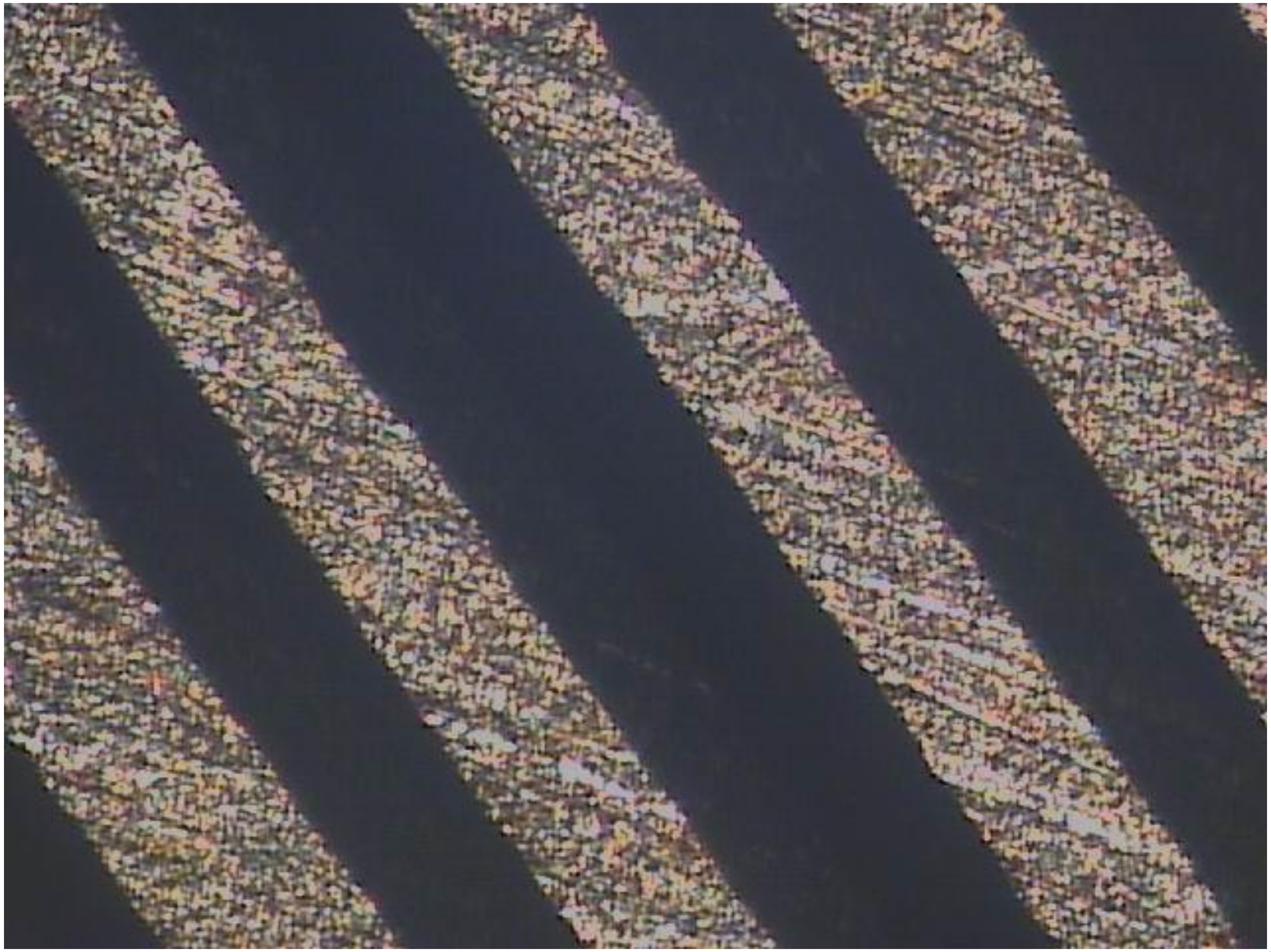
- **Voltage** **1 sec** **3 sec** **5** ***sec*** ***7***
  sec
- 500 1 4 5 5
  ½
- 550 3 5 ½ 7 8
- Note: the next results were tested the following day, with some reduction in resist sensitivity.
- 600 3 6 6 7
- 650 3 6 7 8
  ½
- 700 4 7 8 8
  ½

Stauffer Test Panel



Stauffer resolution panel

0.004” and 0.007” tracks



SEM of 100 micron opening

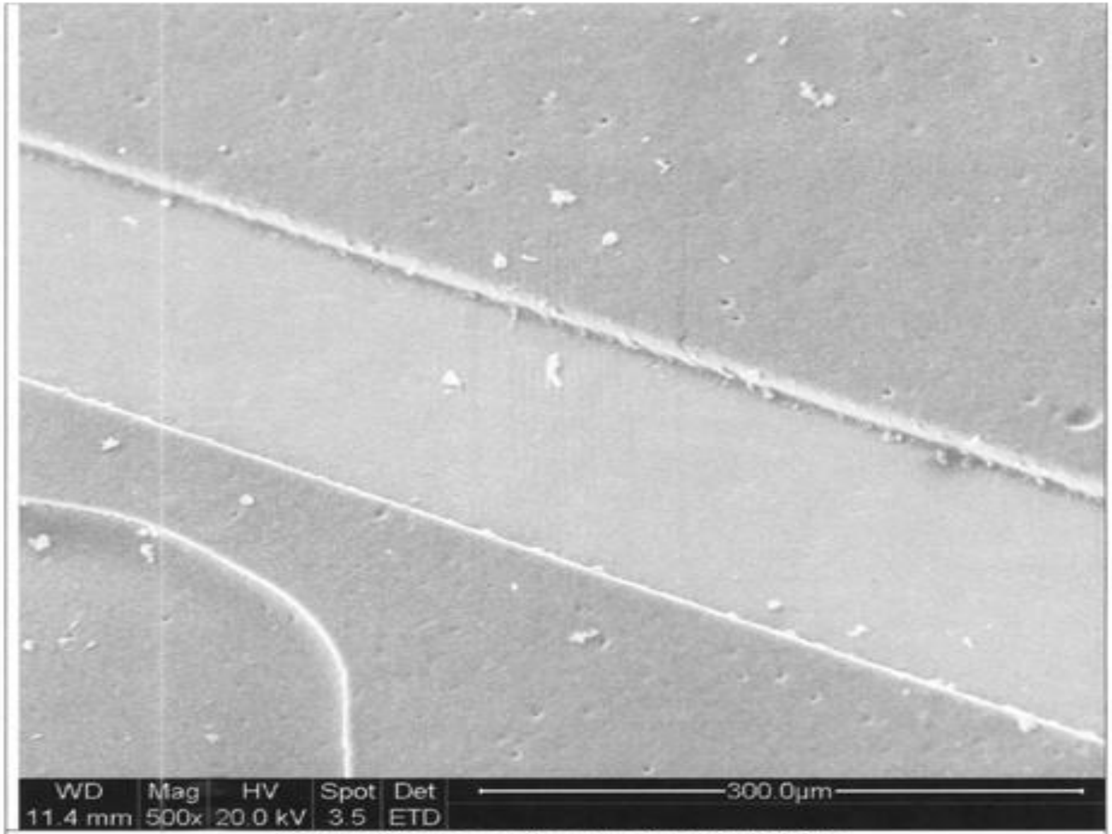
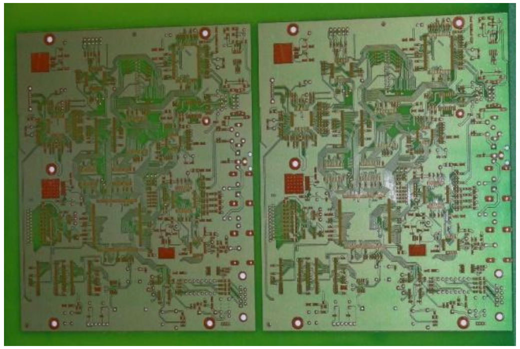


Fig. 7 SEM image of sample Unit #5 (500X)

Registered SM panel

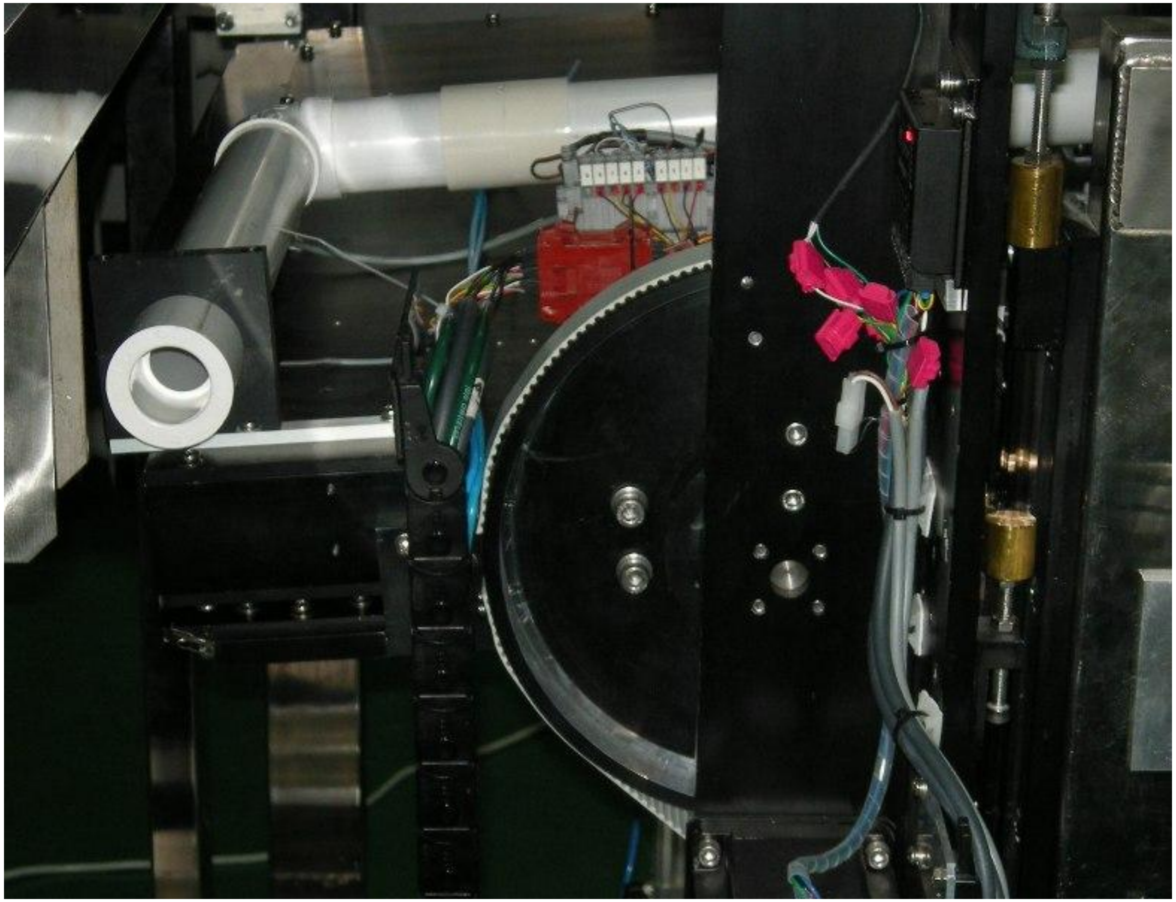


Open machine showing service access

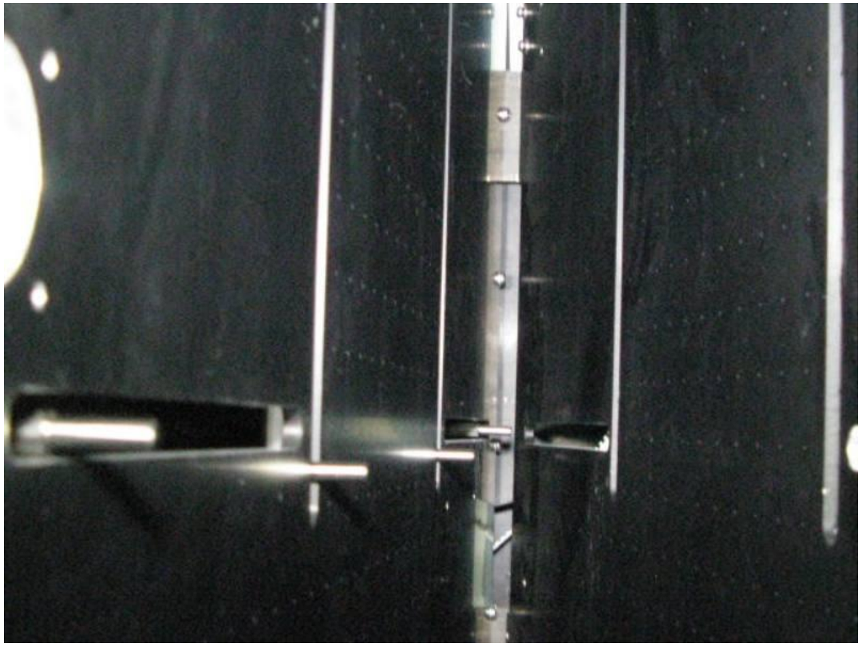
Alignment Stage extended

Glass tray

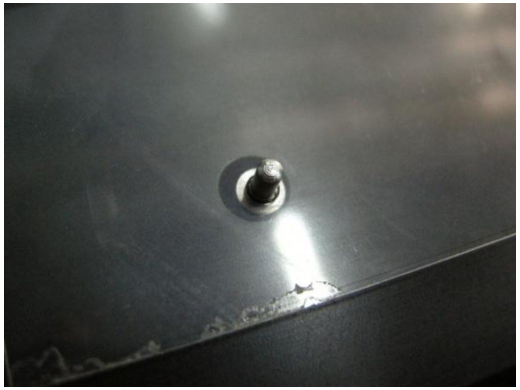
Flipper in Load Position



Flipper module opened



A/W mounting area



Platen surface

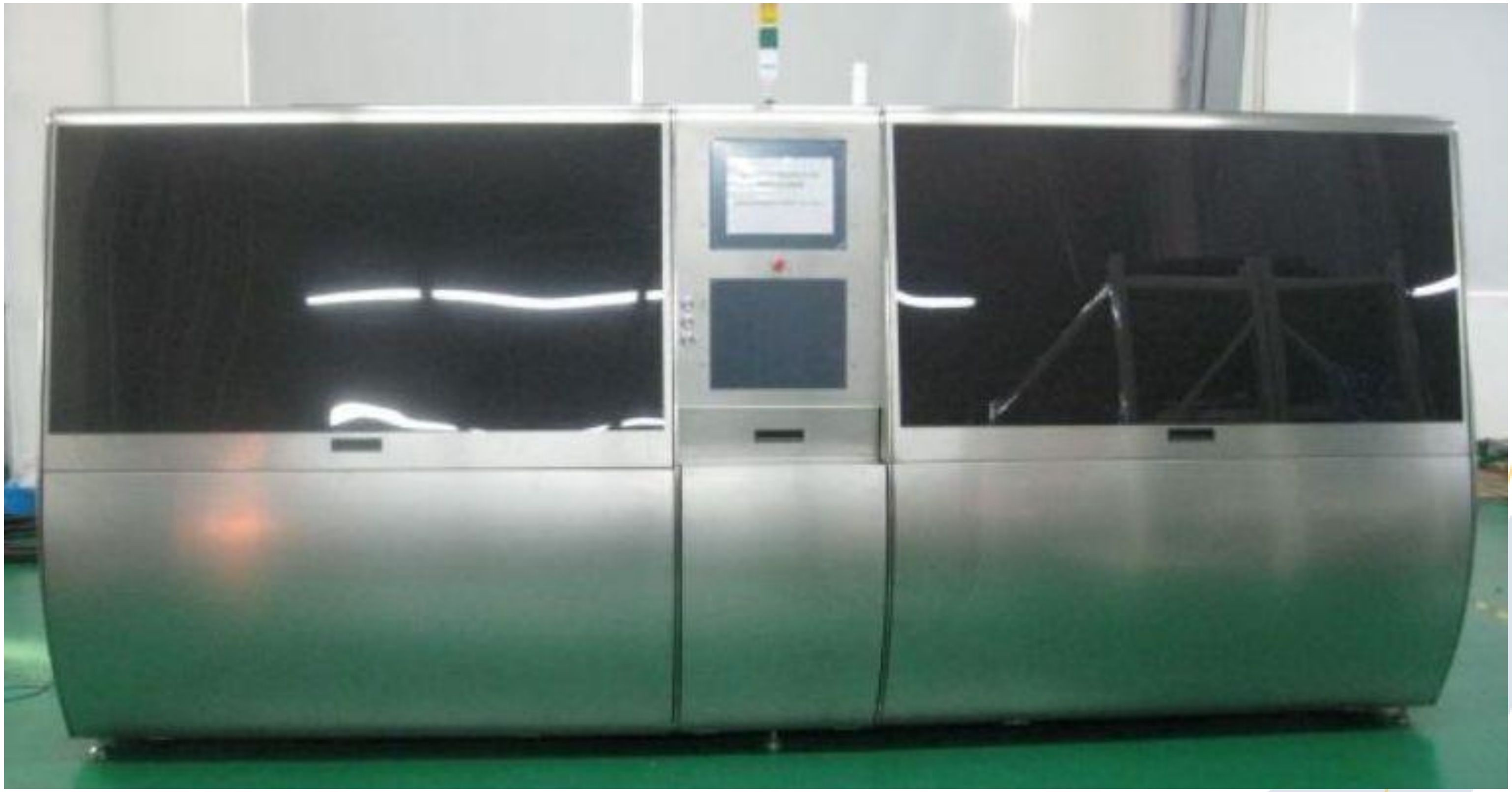
Platen float system

New vacuum pump system

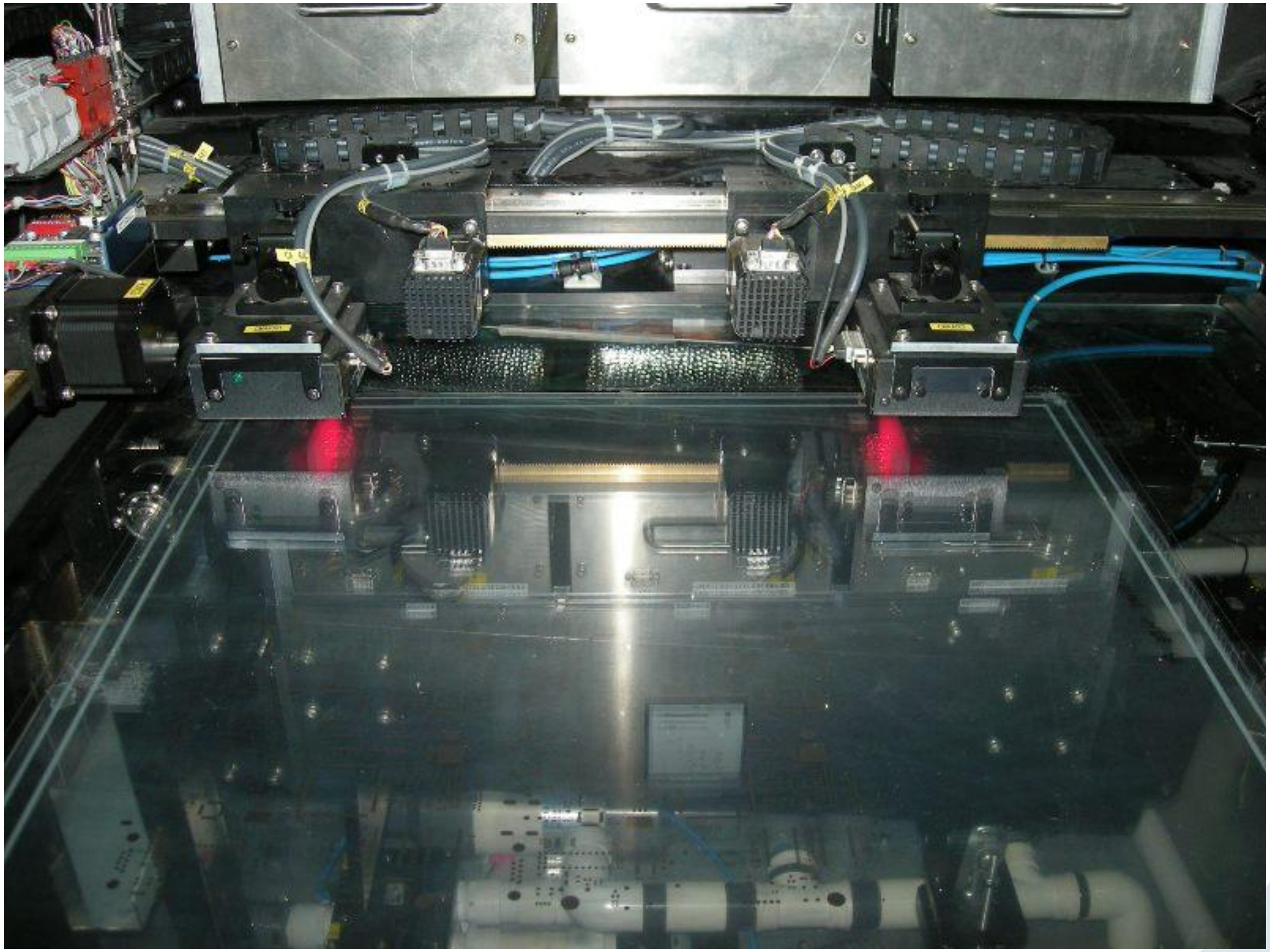
Shim system (patented)

ORC Model X-Pose 120

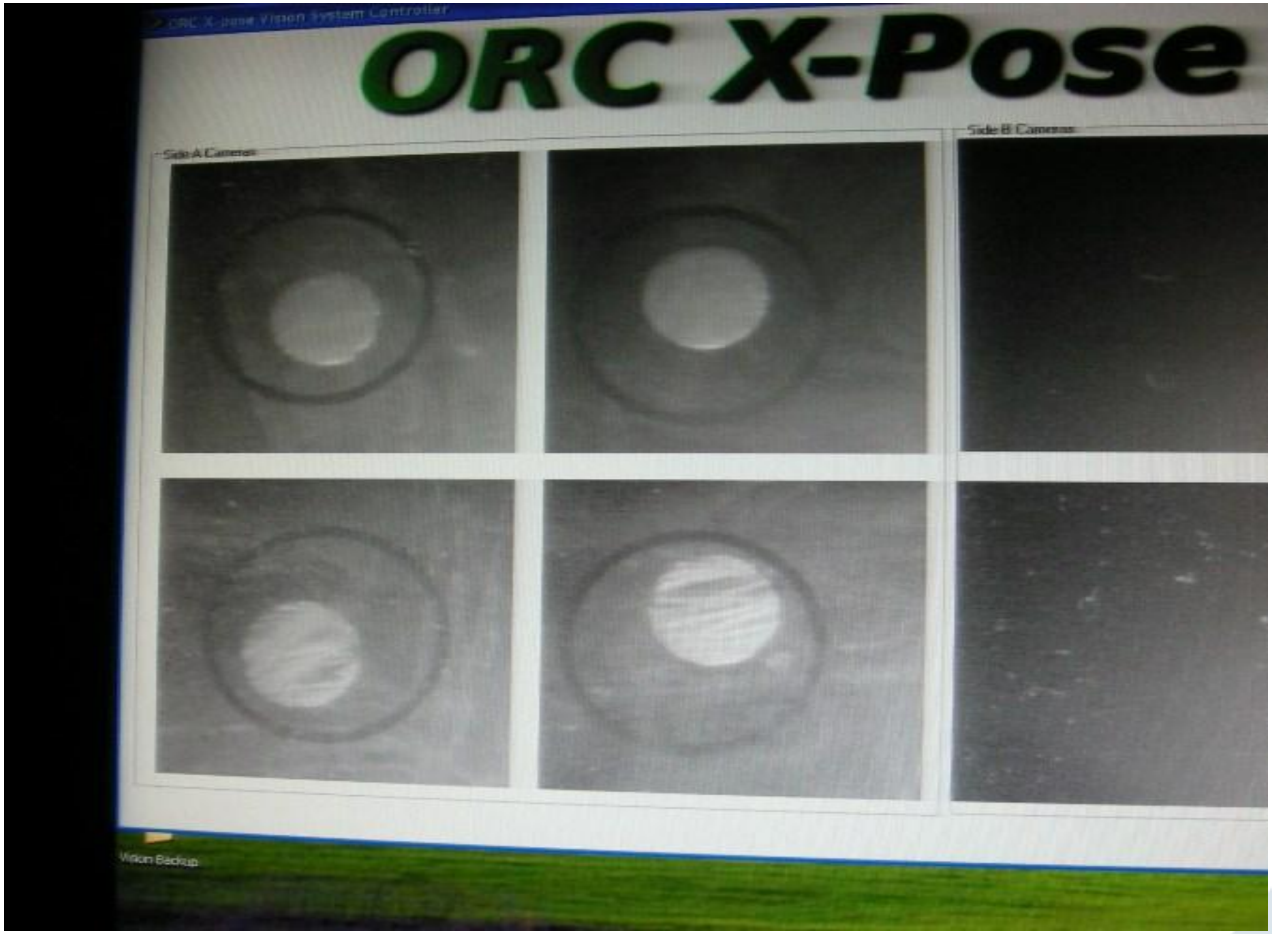
- *Alpha Machine*



CCD Cameras



CCD camera alignment



CCD Registration