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CLEANING OF A THERMAL VACUUM CHAMBER WITH SHROUDS IN PLACE

William R. Bond
NSI Technology Services Corporation

ABSTRACT

In February, 1991, a failure of a rotary booster pump caused the diffusion pumps to backstream into a 10' x 15' thermal vacuum chamber. Concerns existed about the difficulty of removing and reinstalling the shrouds without causing leaks. The time required for the shroud removal was also of concern. These concerns prompted us to attempt to clean the chamber without removing the shrouds.

INTRODUCTION

Facility 225, a 10' x 15' thermal vacuum chamber, was built and installed at Goddard Space Flight Center in 1962. The chamber was first located at Building 4 where it remained until 1987. For the majority of this period the chamber was used as a solar simulator. During the normal solar simulator test the shrouds were flooded with liquid nitrogen at 30 psi. At the conclusion of the test the liquid was dumped. The thermal system was then operated in a gaseous mode to return the system to ambient temperatures. Heating was achieved by the frictional effects resulting from the circulation of nitrogen, and by the heat generated by the 150 horsepower blower motor. Occasional chamber bake out procedures raised the shroud temperature to 100 °C. Towards the end of the Building 4 period a new project changed the operation from that of a solar simulator to a pure thermal vacuum system. Operating temperatures for this project ranged from ambient to 50°C.

During the end of 1987, and the beginning of 1988, the chamber was disassembled, moved approximately ⅓ of a mile, and reassembled in the main Space Simulation Laboratory in Building 7. The original design had welded connections between the shrouds and the external thermal system piping. The removal of the shrouds for the relocation required cutting the connection and bending the shroud to allow the connection stub to clear the chamber wall. This was an approximate 6" deflection of the * 111" diameter shroud. In Building 7 the shrouds were fitted with flanges and connected to the thermal header through a bellows assembly. Although the welded connections were gone, the ends of each shroud were now held in a fixed position by support clamps.

The recommissioning of the chamber occurred in August of 1989. Because of cost considerations, with the exception of the shroud connections and piping, the thermal system was unchanged. The major vacuum components were also substantially unchanged. The rotary piston pump and rotary lobe booster pump did not come with the chamber but were of similar age to the originals. Inside the chamber the thermal system consisted of front and rear shrouds and four pairs of side shrouds. (Figure 1) Shrouds 3 and 5 have cutouts to allow an opening for the old solar simulator source.

Besides the previously mentioned piston and booster pumps, the vacuum system consists of three diffusion pumps and a small rotary piston pump. All of the mechanical pumps are located in a machine room in the basement. (Figure 2) The three diffusion pumps are located at the back of the chamber behind the rear shroud. No valves exist between the diffusion pumps and the chamber. The diffusion pumps use an oil described as 100% mixed isomers of pentaphenyl ether. Based upon the MSDS provided with the oil, the boiling point is 476°C and the flash point is 288°C.

SYSTEM FAILURE

On the evening of Tuesday, February 5, 1991, Facility 225 was performing a "bake out" of a test fixture. At 22:50 an event occurred that was documented by the following "Error Malfunction Report." "All 3 DPs went off line, GN_2 blower off, cold traps stop filling, chamber pressure at 6 Torr. Informed mechanical and electrical maintenance." Inspections of the chamber and vacuum equipment on the morning of the 6th revealed that the booster pump input shaft had fractured. This fracture allowed air to enter the foreline causing the three diffusion pumps to backstream coating the chamber walls with diffusion pump oil.

Initial Response

An emergency response team was established to return the chamber to service as quickly as possible. The initial meeting was held after members of the team had an opportunity to view the chamber and its mechanical components. Technicians, facility and test operations engineers, and the Maintenance and Operations Supervisors were members of the team. At the first meeting the team outlined possible approaches to the cleaning task. The two basic approaches were: 1 Remove the shrouds to allow a thorough cleaning of all surfaces; 2 Clean the chamber without removing the shrouds. At the end of this meeting the team had identified most of the benefits and probable difficulties associated with each approach. The team leader made assignments to determine the availability of personnel and materials for the cleanup project. A second meeting was held in the early afternoon to discuss scheduling for the two basic approaches and to form the recommendations for presentation to NASA.

While it seems obvious that the suggestion of one of these approaches suggests the other, the idea that this chamber could be cleaned without removing the shrouds seemed optimistic at best. The chamber is 25 feet long with a six inch gap between the shrouds and the outside wall. The rear shroud covers, and is close to, the lower half of the back wall of the chamber. Cleaning the chamber without removing the shrouds would probably require a spray of liquid which was complicated by the fact that another facility is operating with people only ten feet from the door of Facility 225. How do we determine that the areas that are hard to reach are actually clean? While the questions about the possibility of leaving the shrouds in place seemed to present serious concerns, so did the alternative.

Removal and reinstallation of the shrouds required that the shroud ends be pulled together at least one and probably two times. (The shrouds would have to be held in the deflected position during the cleaning process to allow only one stress cycle.) Leak checking the shrouds while they were out of the chamber made sense since any leak found could easily be repaired. The shrouds still would have to be leak checked after they were reinstalled in the chamber. Leak checking the back side would be hard. Repairing the back side could well require the removal of the shroud for a second time. Even the flange connections between the headers and the shrouds would be difficult to assemble.

Proposal

The afternoon meeting helped to clarify the proposal that we would be making to NASA. If we could find a chemical that would remove the diffusion pump oil, that would not damage the chamber and whose use was without risk to people, the lab and the environment, we would perform the cleaning with the shrouds in place. The task could be accomplished quicker, for less money and less risk if that chemical could be found. Unfortunately the manufacturer of the diffusion pump oil was recommending the use of freon based solvents or acetone. Both of these materials were unacceptable for spray application in an area where recovery would be very difficult.

Decision

NASA officials approved a parallel effort at the beginning of the cleanup task. This effort would allow the initial work for both cleaning approaches to proceed. If our investigation found a chemical that could satisfy our requirements for a cleaner or solvent, and a satisfactory method of application, we would proceed with the shrouds in place. While the investigation into chemicals was going on, the assembly and improvement of the shroud removal fixture would be undertaken.

CLEANING EFFORT

Parallel Tasks

On Saturday, February 9th, the recovery effort officially began. The work effort was to continue 24 hours a day until the chamber was recertified. Work began by removing the test cart and payload fixture. The auxiliary test equipment and the cart rails were removed next. By the end of Monday all three of the diffusion pumps had been removed from the chamber and transported to an available work area. Once the diffusion pumps were in the work area the process of removing the oil began. Because of the viscous nature of the oil, removing the oil required the application of heat and two days to complete. Most of the old shroud removal fixture had been located and the disassembly of the failed blower had begun. The blower disassembly was completed the next morning.

Because the large Space Environmental Simulation Chamber (SES) had eight identical booster pumps, the cause of failure of the blower had additional significance. We completed the disassembly of the pump on Tuesday. Our evaluation of the failure was that fracture was due to fatigue. Because of the importance of the answer to the other facility we contacted the Materials Branch of the Office of Flight Assurance to conduct an analysis of the failure. The final report of the failure concluded that the failure was "a result of combined torsion and bending fatigue." As the result of this investigation engineering specified the use of new booster pumps for the SES.

Chemical Investigation

The investigation into possible cleaning solutions ran through many paths. Numerous telephone calls were made to firms that supply vacuum equipment and others that use or install diffusion pumps. We found two chemicals that seemed to be worth testing. Both were identified as glycol ethers. One was identified as a mixture of 1-Methoxy-2-propanol (97%) and 1-Methoxy-1-propanol (3%). The second chemical was Dipropylene glycol monomethyl ether (99%). The chamber door was used to test these chemicals. Since a spray system had not yet been developed, each chemical was tested by pouring it over a contaminated area. A second area was subjected to a wipe using the chemical. We then asked the Polymers Section of the Materials Branch to test the four areas. They reported that the Dipropylene glycol monomethyl ether appeared to be the best choice. We had checked the four test areas using a black light and had come to the same conclusion.

Application Method

While the chemical evaluation was taking place, other technicians and engineers were busy with the application and removal problem. The design of the chamber has eight bellows assemblies along the bottom centerline. Any liquid in the chamber will fill these assemblies with approximately three gallons of the solution per assembly. We concluded that both the spray and the removal of the solution could be accomplished with an air operated polypropylene diaphragm pump. A wand was made using 0.5" OD stainless steel tubing. A nozzle was made locating six 0.060" holes spaced evenly around the diameter. Operating the pump at 40 psig produced a flow of one gpm. A series of 0.25" OD flexible copper tubing wands was made to remove the liquid from the bellows assemblies. The end of the removal tube was inserted in the bellows assembly through a small gap that existed between the left and right shroud halves. The insertion was difficult. The wand was inserted as far as it could be reasonably inserted. This left varying amounts of liquid in each bellows assembly.

Decision Made

The decision to proceed with the attempt to spray clean the chamber occurred on Monday the 18th. The effort to revise the shroud removal system was also complete at this point. This provided a fall back position if it turned out that the spray wash did not work. The cleaning effort for roughing and other lines and the reassembly of valves that had been serviced and leak checked took until the 19th.

Preparations

A cleaning procedure was written and signed by company and NASA representatives. The procedure was more of a safety document than a true cleaning procedure. The first line of the section that discussed the actual cleaning procedure stated: "The operation will not begin until all safety measures have been taken." It included information taken from the MSDS as well as the MSDS itself. Personnel directly involved in the cleaning were required to use breathing apparatus and face shields.

Final preparations for the cleaning effort took place on the 19th and the early morning hours of the 20th. Loose mylar and other bits of testing debris were vacuumed out of the chamber. The rear anchor beam and pedestal for the shroud removal fixture were removed. Ports that had been opened during the first stages of the project had to be blanked off. The cleaning chemical's full drum weight was recorded as were the empty drum weights of the containers that would collect the used chemical. Hose connections were made to drain the solution to the collection drums in the basement. A rubber sheet and plywood dam was installed at the front of the chamber.

Fume and mist control was established using curtains and an exhaust fan. 20 foot long plastic curtains were hung around the entrance to the chamber. A flexible exhaust duct attached to an exhaust fan was inserted through one of the diffusion pump ports at the back of the chamber. The roof exhaust fans as well a fans that exhaust air from the basement were also operated. This combination of containment and exhaust maintained good air quality in both the lab and the basement.

Cleaning

The actual spray cleaning of the chamber started at 0600 hours on the 20th and was completed at 0800 hours on the 21st. The chamber had been sprayed with chemical twice. Since the chemical is classified as being infinitely soluble in water we followed these applications with two clean water rinses. The last step of this phase of the project was to pump as much of the liquid as possible out of the bellows assemblies. The Polymers Section took five test samples. Three of the samples were rated excellent One sample taken next to the chamber lip at the top showed a trace of diffusion pump oil. Since a second sample also taken from the top but further into the chamber showed no sign of the oil, we treated this area by hand wipe. The last wipe sample showed no diffusion pump oil but had trace materials "from earlier bake outs." Black light examination showed the chamber walls to be in excellent condition. We did find that over spray had contaminated parts of the black inside shroud surface. We wiped the black surfaces with alcohol. This successfully removed the contamination.

The time from the 22nd until the 28th was spent reassembling the chamber and leak checking. This included installing the new booster pump that we had purchased on an emergency basis. (In spite of the emergency the blower procurement was still done on a competitive bid basis.)

On Thursday, February 28th, at 0645 hours we began the pump down of the chamber. By noon we had to change the oil in the piston pump because of the accumulation of moisture. This procedure was repeated six times during the first 30 hours. As we pulled a vacuum on the chamber the liquid in the bellows cooled, eventually producing frost on the outside of the bellows. Based upon the frost lines, and the approximate 3 gallon capacity of the bellows, we had between 5 and 8 gallons of liquid trapped in the bellows. We started the thermal system at approximately 0830 hours on March 1st. The initial setting was 25°C. The temperature was set to 30°C at 0900 and raised to 40°C at 0930. At 1000 we set the temperature to 50°C with plans that this would be the final increase until the moisture was driven off. The last of the frost disappeared at 1045 hours and the final piston pump oil change was performed. The operations technicians started the diffusion pumps at 1300 hours on the 1ST. They decided to maintain the temperature at 50°C. until 1900 hours. At 1900 hours the technicians began to increase the set point in 25°C steps to 100°C with a final increase to 120°C. At 2200 hours the chamber temperature was 120.8°C and the pressure was 1.3×10^{-5} Torr. Technicians held the chamber at the 120°C set point for 48 hours. At 1300 hours on March 2nd the pressure reached 3.7×10^{-6} Torr. The chamber was shut down on March 3rd. Personnel took test samples to be evaluated by the Polymers Section were taken at 2240 hours.

Results

The test samples taken after the initial chamber bake out showed the presence of both the dipropylene glycol monomethyl ether and the diffusion pump oil. The total residue on the cold finger was 28.8 mg. A sample was also taken from the scavenger plate. (Table 1) The bake out had been resumed before the test results were back from the Polymers Section. On March 7th a sample was taken from the cold finger. A second set of samples was taken on March 11th. By this time the total residue on the cold finger was reduced to 1.3 mg. Although both chemicals were still present the lab report concluded, "The smaller amounts of residue seem to indicate that a satisfactory lever for testing flight hardware is being approached."

The need to resume work in this chamber was made easier by the fact that the first jobs that were scheduled were fixture and tool box bakeouts. Based upon the March 11th results, NASA proceeded with the fixture bakeout. Neither dipropylene glycol monomethyl ether nor diffusion pump oil were listed in the test reports of cold finger samples taken at the conclusion of the bakeout on March 15th. The diffusion pump oil was still present on the scavenger plate. The next bakeout was the tool box. Samples from March 20 from both the cold finger and scavenger plate were clear of both chemicals.

Time and Costs

Not including the bakeout time, the cleaning of Facility 225 had required 1770 hours of technician effort. Estimates for the removal of the shrouds were between 2220 and 2780 hours. Since the normal level of effort was 96 hours per day even the lowest estimate would require and additional 4.5 days. Beyond that, however, we would have had to depend upon outside services for insulation and possibly certified welding as well.

The material cost, not including the replacement booster pump and diffusion pump oil, totaled less than $2500. We estimated that insulation work would add $6000 and, if required, welding work would have added another $4000.

CONCLUSION

When faced with a requirement to clean a thermal vacuum chamber, the possibility of a clean up without removing the shrouds should always be considered. Where shroud removal would be the normal, although difficult, approach to cleaning time can be gained by testing. Test coupons coated with diffusion pump oils, or other potential contaminates, should be treated with cleaning chemicals to determine the agents effectiveness.

A regular Preventive Maintenance program including nondestructive examination of all rotating, or otherwise high stress level, equipment should be considered for all components that are a part of the vacuum boundary. Although this will not eliminate the need to clean a chamber, it will minimize the unexpected failure.

Table 1
Residual Contamination After Completion of Each Bakeout

Sample Date	Sample Source	Residue	Contamination
3/4/91	Cold Finger	28.8mg	1. Dipropylene glycol monomethyl ether.
	Scavenger Plate	1066mg	1. Dipropylene glycol monomethyl ether. 2. Diffusion pump oil.
3/7/91	Cold Finger	2.3mg	1. Aliphatic hydrocarbons 2. Diffusion pump oil. 3. Esters 4. Dipropylene glycol monomethyl ether. 5. Organic acids.
	Scavenger Plate	N/A	N/A
3/11/92	Cold Finger	1.3mg	1. Diffusion pump oil. 2. Aliphatic hydrocarbons 3. Small amounts of esters 4. Small amounts of Dipropylene glycol monomethyl ether.
	Scavenger Plate	48.6mg	1. Aliphatic hydrocarbons 2. Diffusion pump oil. 3. Esters 4. Traces of Dipropylene glycol monomethyl ether.
3/15/92	Cold Finger	0.1mg	1. Aliphatic hydrocarbons 2. Traces of butoxy compound
	Scavenger Plate	17.4mg	1. Aliphatic hydrocarbons 2. Dibutyl phthalate 3. A butoxy compound 4. Lauric acid 5. Diffusion pump oil.

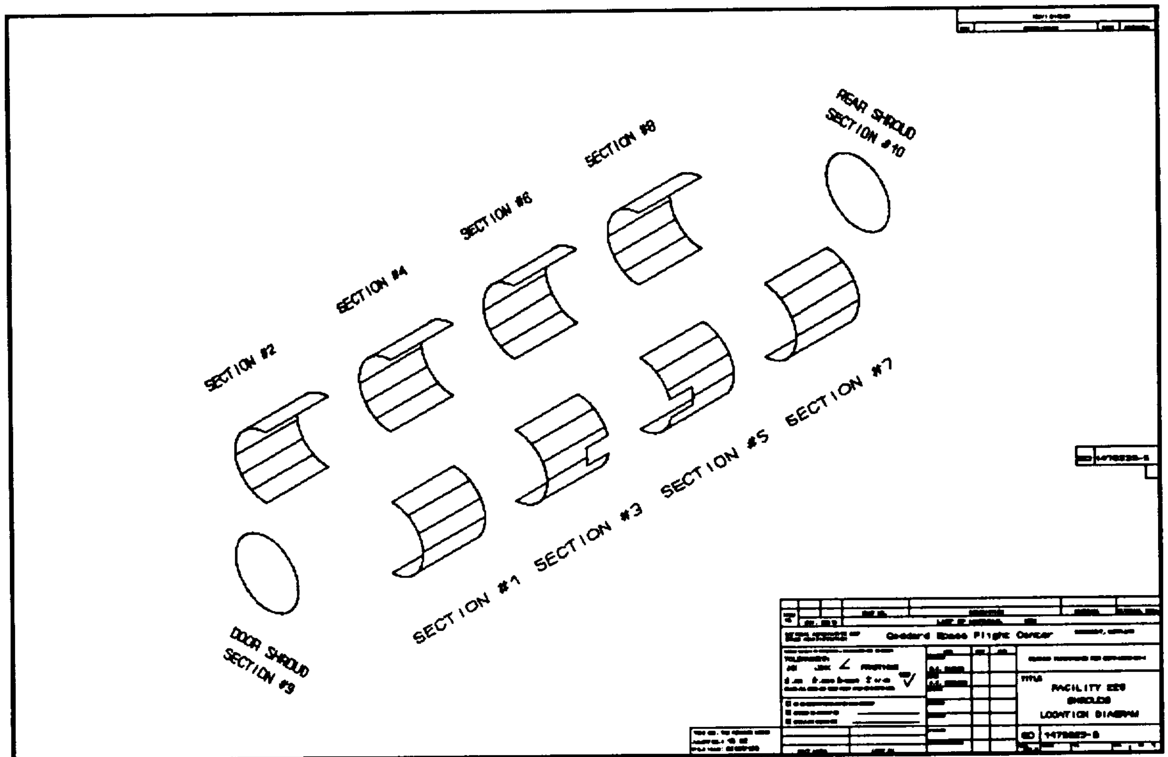

Figure 1 - Facility 225 Shroud Arrangement

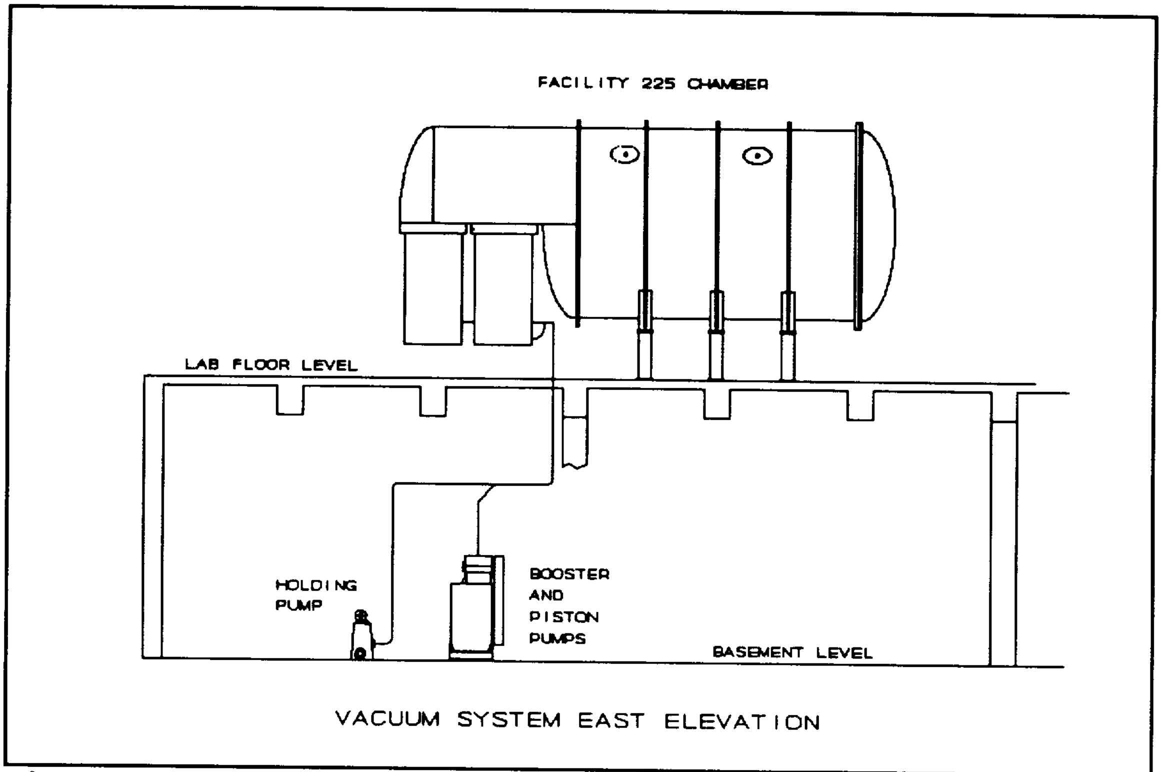

Figure 2 - Facility 225 Vacuum Pump Locations