51-14

THERMAL SYSTEM UPGRADE OF THE SPACE ENVIRONMENT SIMULATION TEST CHAMBER

Ashok B. Desai
Environmental Test Engineering and Integration Branch
Engineering Services Division
Goddard Space Flight Center
Greenbelt, MD.

ABSTRACT

The paper deals with the refurbishing and upgrade of the thermal system for the existing thermal vacuum test facility, the Space Environment Simulator, at NASA's Goddard Space Flight Center. The chamber is the largest such facility at the center. This upgrade is the third phase of the long range upgrade of the chamber that has been underway for last few years. The first phase dealt with its vacuum system, the second phase involved the GHe subsystem.

The paper describes the considerations of design philosophy options for the thermal system; approaches taken and methodology applied, in the evaluation of the remaining "life" in the chamber shrouds and related equipment by conducting special tests and studies; feasibility and extent of automation, using computer interfaces and Programmable Logic Controllers in the control system and finally, matching the old components to the new ones into an integrated, highly reliable and cost effective thermal system for the facility. This is a multi-year project just started and the paper deals mainly with the plans and approaches to implement the project successfully within schedule and costs.

INTRODUCTION

The current test facility has been in operation ever since it was commissioned about 35 years ago. The design, fabrication and installation of all its sub-systems, main components and controls, are almost that old. Besides the older technology of the systems and components, its operational and maintenance costs have been quite large. It has needed a relatively large number of operators; the controls being fully manual have required very close monitoring by highly trained and experienced technicians; most of the components are in constant need of preventive and corrective maintenance. Observatory level tests have required large number of technicians at the two floor levels, adding to the costs. The LN_2 consumption cost is also a large portion of running a test in the chamber.

The chamber shrouds in similar facilities and of same age at other locations have had structural failures and have been replaced with new ones. The shroud panels undergo large deflections. The panel to cross-over tubing interface welds were suspected to be the most stressed areas and vulnerable. The GN_2 flows through the various circuits are not balanced and difficult to tune.

The thermal system upgrade would reduce, if not eliminate, many of these costs, improve reliability, more accurate cost estimates, efficiency, and with PLC based control system, reduce operational costs with lesser number of technicians.

EXISTING FACILITY

The test facility is a vertical chamber, about 30 ft. in diameter and 40 ft. high, shown in Fig. 1. The thermal and vacuum system components are distributed from the basement to second floor of the building. It is equipped with eight cryopumps and a turbo-molecular pump, to achieve ultra-high vacuum. The thermal environment variations are provided through a cylindrical side shroud, a bottom shroud and a combination of a frustum and disc type top shrouds. Computer data terminals, with packaged software routines, are used to monitor the payload temperatures. Fig. 2 shows a typical thermal system control panel with manual valves and Fig. 3 shows the PLC based control system panel that was part of the vacuum system upgrade.

The original chamber had diffusion pumps with LN_2 cooled elbows. This system was upgraded recently by replacing the old diffusion pumps and LN_2 cooled elbows with new cryopumps and sliding main valves. A programmable logic controller (PLC)-based interface panel was installed that gives access to and helps monitor chamber pressure, cryopumps and its mechanical pump health, any fault or operator warnings and alarms. All the information is available to the operators through a color graphics display. This capability was included with a view to potential remote/automatic operation of the chamber, for simpler tests, with the vacuum system and the new thermal system, fully integrated.

Thermal System

The thermal shrouds are of aluminum tube-in-sheet arrangement, with both liquid and gaseous nitrogen flow through the tubing. The three main shroud circuits of the current thermal system are operated from a central thermal skid. The GN_2 is made in the main vaporizer and forced through the tubing by a central GN_2 compressor. Separate pumps circulate the LN_2 when called for to flood the shrouds. The tubing had been formed by forging two flat panels together and passing through high pressure rollers. The panels are attached to mechanical supports off the chamber shell. The tubing run vertically through the full height of the chamber. The two rows of panels stacked vertically are connected by interconnecting tubing. The ends of the tubing are connected by welding separate tubes and elbows. This makes for a long tube runs for GN_2/LN_2, resulting in large temperature gradients and pressure drops. Fig. 4 is an interior view showing the vertical panels of the side shrouds and GN_2 tubings.

Thermal Shrouds

Top Shrouds: These are made up of 36 separate panels in frustum shape. There are two parallel LN_2 and four parallel GN_2 circuits. It is designed for a thermal load of 72 watts/sq. ft. The top of the frustum end up in the dome of the chamber which currently has solar lamps-and-lens assemblies, forming the old, decommissioned solar simulator.

Side Shrouds-- A total of 36 separate panels make up the side shroud into a vertical cylinder of about 28 ft. inside dia. and about 38 ft. height. There are six LN_2 and twelve GN_2 parallel circuits.

Bottom Shrouds-- A 30 ft. dia. disc made from five separate panels form the bottom shrouds. There are five parallel circuits, designed for a maximum of 275 watts/sq. ft. thermal load.

LN_2 Subcooler

A subcooler provides a single-phase LN_2 to the shrouds. Its current capacity is to handle 200-KW thermal load through the circulating LN_2. It has two 20-hp, 150 gpm LN_2 pumps; vacuum jacketed heat exchangers, control valve box and electrical control panel.

Warm GN_2 System

The warm GN_2 system heats or cools the chamber shrouds between the temperature range of -65 ^{0}C to +85 ^{0}C. The system consists of four heat exchangers, a compressor and a refrigeration system, control valve box and electrical control panel. A 125-hp compressor circulates GN_2 with a pressure range of 115 to 180 psia. The R-22 refrigeration system, with a cooling capacity of 10 tons at -80 ^{0}C. cools the GN_2 prior to circulation.

The chamber also has a GHe refrigerator to provide gaseous helium at 15 K. The refrigerator has a capacity to handle 1-kw thermal load at 20 K. The system is skid mounted and was upgraded in 1994.

THERMAL SYSTEM DESIGN

The new thermal system design has two main aims, namely, to increase the existing temperature range along with the overall thermal capacity and to include a control system to enable remote, and for simple tests, automatic operation.

The main design requirements will be, temperature Ramp rates of,

- 40 ^{0}C/Hr. over -185 ^{0}C to +20 ^{0}C,
- 34 ^{0}C/Hr. over +20 ^{0}C to +150 ^{0}C for heating and
- 30 ^{0}C/Hr. over +20 ^{0}C to -130 ^{0}C for cooling.
  And
- Maintain stability of $\pm$ 2 ^{0}C at any temperature between -130 ^{0}C to +150 ^{0}C,
- Shroud temperature uniformity of 10 ^{0}C over the full range.

The design will focus on the following basic features:

- Skid mounted, modular assemblies.
- Handle the top, the side and the bottom shrouds as the three main zones and provide thermal conditioning to the zones.
- Utilize the existing vacuum jacketed lines.
- Utilize the existing GN_2 compressor.
- Use available plant steam as the heat source.
- Use a PLC based control system, compatible with the existing one for the vacuum system.
- System to be capable of remote operation from other control consoles through appropriate instrumentation and feedback loops.
- With new LN_2 pumps, LN_2 mode will be activated by the control system automatically to provide sub-cooled LN_2 to the three shroud zones, with the shroud temperatures less than -180 ^{0}C.
- A 50 kW of payload heat dissipation to be handled.

UPGRADE OPTIONS

Some of the driving factors that affected the design considerations were: overall cost of the upgrade, technically efficient and reliable system, PLC based control system to be integrated with the vacuum and GHe subsystems, minimum downtime for demolition and installation of new components, schedule of on-going test activities and available funding over the life of the project.

Two options were considered to achieve a balance of the above factors:

Multiple TCUs with Zones

The shrouds to be divided into various zones and supplied with multiple and portable thermal conditioning units (TCUs). A sub-option was to have three sets of TCUs, each for the top, the bottom and the side shrouds. The units could be similar in capacities and design and thus be interchangeable. The side shrouds could be further divided in an upper and a lower half circuits, even a few vertical zones, supplied from separate TCUs. Thus zoned and valved, the top shroud can be moved so as to utilize the lower half of the side shrouds and accommodate smaller test payloads.

Centralized Thermal System

The second option was to replicate the old central system with central heat exchanger and a central GN_2 compressor, with using either the old shrouds in their current configurations or modified in various zones, as discussed above. The system would have new heat exchanger, related piping, control valves and control panels, using the existing heat source and LN_2 supply.

The first option could reduce consumption costs and increase efficiency. High pressure, high density units can be portable enough in size and be economical in design and fabrication costs, being identical units. The units can be interchangeable and replace a unit that suffered a failure. It can provide considerable flexibility and high efficiency. However, the concept would necessitate the shrouds to be modified with extensive manifolds for piping and isolation valves. A lot of cutting and welding of tubing and feeders inside the chamber would be needed to ensure balanced flows and suitable pressure drops for blower type system. It also would require new chamber penetrations for the extra inlet and return piping and valves for each zone. Added to this would be external piping and valves to interface with the sub-cooled LN_2 subsystem.

The second option could reduce equipment and installation costs, as a large single unit would cost less than a multiple units adding up to the same large capacity. This would also be more compatible with the existing shroud configuration. This option would be less flexible and need to be run fully even for a small payload. The zoning of shroud would not make economic sense and reduce the flexibility and efficiency further.

To facilitate the choice between the options, two sets of calculations were carried out to evaluate the required heating/cooling capacities needed, the maximum temperature ramp rates achieved, the required gas flows and related pressure drops and thus the needed capacities and physical dimensions of units for each option.

The results indicated that the size and number of TCUs needed were much larger than reasonable for the space, power and utility requirements around the facility. The associated pressure drops in the long tubing would be too large for the blowers in the TCUs to handle. The consensus opinion was to go for the central system. One more critical decision required for choosing the centralized system was that of determining the potential "life" left in the present shrouds.

APPROACHES TO SHROUD LIFE EVALUATION

As a consideration for a full "turnkey" project to replace the thermal system, the chamber shroud replacement was also a major factor. The existing shrouds pose some problems, namely, they are 35 years old, had leakage problems earlier, limit flexibility in the design of the new thermal system and the old paint on the shrouds limit higher operating temperatures.

The actual number of thermal cycles imposed on the shrouds were estimated, based on the test history, to be no more than 400 to 450 over its 35 year operation. A surefire indication of shroud components failing is large and small leaks under vacuum. Welded joints between the tubing, under fatigue induced by thermal cycling were the most obvious points of scrutiny. Any extra loads imposed on adjacent panels and tubing due to mechanical restraints, asymmetrical flows and warping of the whole shroud cylinder moving under thermal expansions and contractions, were also planned to be investigated.

A large chamber, at another location, was earlier tested very extensively and critical components analyzed through finite-element techniques, for investigation of the weld joint cracks in the shroud tubing. Ref. 4 describes this study. This precedent allowed the development of a test evaluation plan.

Two outside consultants were contracted to develop detail test methods, procedures and carry out the tests. The analyses and review of the gathered data resulted in conclusion and recommendations for low cost modifications to extend the potential "life" in the thermal shrouds.

Phase 1: Nondestructive Testing:

Eddy current and/or dye-penetration testing of the welds in the cross-over connections in the top, center and bottom panels. Fatigue type indications in the toe and heat affected areas were to be inspected in the welds. The indications, such as porosity, high frequency burns and cold lapping, were judged to be related to the welding process.

Radiographic inspection of the welds in the crossovers, using x-rays, for internal flaws that may be propagating to the surfaces. Radiographic examination showed some crack development in the top crossover tubes at the weld joint with the panel. However, the cracks appeared not be propagating across the tube wall or the weld material. The depths were no more than 10% of the wall thickness and of random occurrence.

Thermograph images of the welds, crossovers and the shroud panels under temperature gradients to record the thermal profiles and effects of flow rates. The thermal imaging of the panels indicated the flow of GN_2 between panels is not uniform and the feed from the manifold is not balanced. This is creating binding and jamming of panels. This is a major factor in inducing inter-panel stresses.

Determination of actual strains and stresses in the areas of the shrouds, under actual, normal thermal cycles. A series of strain gauges and thermocouples were installed on the areas of selected panels and cross-over tubing. Stress/strain measurements under thermal cycling indicated large loads on the feed and the return pipes. Fig. 5 shows the strain gauges and thermocouple locations on the tubes and panels. This was one of the panels selected for investigation. Figures 6, 7 and 8 show the plotted results at the top, middle and the bottom inlet locations of the tubes. The microstrain values measured by respective strain gauges and temperatures by the thermocouple are plotted together. The strain values closely follow the temperatures through the hot and cold cycle in Fig. 6, the weld joint between top tube and the panel. The difference between the two progressively increases from top through middle to the bottom areas of the test coupon. It was concluded that the thermal strain was being countered by large strains of opposite directions, by external mechanical constraints on the tubes and especially the inlet feeders off the manifolds. Upon inspection, some of the U-bolt type supports on the feeders were found to have sheared off or severely distorted. The adjacent panels were also appeared to be binding at the sides and contributing further. These mechanical fatigue loads are more detrimental to the weld joints.

Phase 2: Destructive Testing:

Determination of the fatigue strength of the material of the panels, tubing and welds and thereby, the life expectancy. A set of test coupons were cut out of the shroud panels, with a section of the cross-over tubing included. One set of panels were set up with external sources of LN_2 and warm GN_2. The setup was then subjected to almost 1110 cycles between LN_2 and GN_2 at about +85 C. The pieces of tubes and panel weld joints were inspected with a scanning electron microscope which revealed series of ridges that indicated effects of progressive incremental fatigue corresponding to the thermal cycles. Fig. 9 through 12 show the sample piece, the crack propagation, its width and the effects of thermal fatigue. The crack was estimated to develop and propagate after almost 900 cycles. This appears to be almost more than twice the actual cycles, the shrouds have undergone in real time. This indicated that the thermal fatigue, as suspected at the start was not the main destructive factor. Another set of panels were configured to be subjected only to mechanical strain loads, representative of the actual measured loads on the shroud assembly.

Performing thermal stress analyses using finite-element based math models of the suspect areas and geometry of the shroud panels was an additional tool available for use. These analyses can establish maximum strain conditions in the structure and only peak strain areas would be analyzed further in detail. To reduce cost and fit the schedule, this option was not pursued.

The cost estimates for the full test evaluation were less than 5% of the total projected cost of a new shroud system. That appeared to be a prudent investment to be able to quantify the potential problems, causes and required modification to extend the life expectancy of the shrouds.

Modifications and Repairs

Top Shrouds

The removal of Solar Cell feedthroughs, purge system and lens assemblies, associated with the old solar reflector subsystem, in the chamber top dome necessitated replacing the top shroud to provide shielding of the payload from the dome walls.

In the first phase of the project, a 29-ft. diameter flat disc top shroud will replace all the 127 panels and the frustum shaped old shroud. The frustum does not add to the working volume of the chamber, as the dome slides out on a pair of rails for loading and unloading of the test articles. It would need only one of the thermal circuits and smaller number of connections. this will eliminate extra feedthroughs and circuits, reducing capacity requirements on the compressor and the thermal system; also ensuring operational and consumption cost savings.

Side Shrouds

The feed and return piping supports, imposing the mechanical loads against the panel movements, will be redesigned with sufficient clearances and Teflon coated pads. The panel interlocks will also be repaired with bolts to take up shear and edges with clearances to relieve the binding of the panels. The feeder manifold and the piping will be modified to balance the flows as much as possible.

AUTOMATION IN CONTROL SYSTEM

The old electro-mechanical relays based manual control system with complex logic and interlock circuitry, has been replaced with PLC based system for the vacuum system of the chamber, as mentioned earlier.

The two control systems will be connected together and integrated into a Local-Area-Network that will also include other chambers in the labs. The goal is to use the Man-Machine-Interface (MMI) software package to automate the controls. The system would be flexible enough to access, set, control and operate from remote operator consoles also. The network is planned to be further integrated with the data acquisition system to provide real time payload and facility system parameters from various PC based access points.

It will be possible to program a bakeout temperature profile with ramp rates, bakeout soak setpoints, contamination monitoring and feedback to terminate or change soak temperature setpoints and finally to bring the thermal system to ambient at the end of the bakeout.

The PLCs are highly flexible, modular and expandable. The programs can be changed and revised as the needs change. The upgraded thermal system is planned to have a similar PLC based control system.

The basic elements of such a system are:

1. The main application or the process to be controlled
2. Input devices
3. Input modules providing signal conversion and protective interface
4. Programmable Logic Controller (PLC)
5. Control logic program for the application process
6. Output modules providing signal conversion and protective interface
7. Output devices such as lights, solenoids and motor controls
8. Man-Machine-Interface software for control and monitoring of the application process

The PLC itself includes these main components:

- Central Processing Unit (CPU)
- Memory
- Control logic program stored in the memory
- Power Supply

FUNDING PLANS, TASK PRIORITIES AND SCHEDULE

Multi-year funding

The Project for the upgrade, as planned, has a four year timeline. All the tasks of project definition, development of design philosophy, specifications, procurement process and demolition of old components and installation of new ones have been planned to correspond to the total funds committed for each of the four years. A multi-year spending plan, in the current overall budget environment becomes a challenge in itself. Detailed spending plans have been developed, based on assumptions about the availability of annual portions of the total funds.

Task Priorities

The various tasks have been prioritized, divided and spread over the fours years to correspond to the funding for those years and the planned and future test schedules. The goal has been to minimize the down time, protect existing subsystems and components from demolition and installation activities and preserve the cleanliness integrity, as much as possible.

CONCLUSION

The series of tests on shroud material, tube welds and piping were a key element in quantifying the potential life of the shrouds and helped in deciding not to replace the shrouds and piping. This provided a major component of savings in cost and time to the project. That also helped avoid the potential problems of welding new piping, fittings and feedthroughs with a new shroud, leakage and extensive cleaning.

The goals of reducing operational costs, increasing efficiency of LN_2 consumption, accurate and predictable controls and test cost estimates can be achieved with PLC based control system and corresponding algorithm sophistication. This requires compatible valves and other process control devices and mechanical and thermal components. The environmental testing lab at Goddard center already has upgraded another chamber with PLC based control system. The advantages of efficiency, wider temperature ranges and reliability in this thermal system has been a foundation on which the SES upgrade was undertaken.

Fully integrated thermal and vacuum chamber under such control system is the way to establishing a state-of-the-art environmental facility for the new, highly complex and sensitive flight hardware for future spacecraft and instruments.

REFERENCES

1. *Operating Procedure for the Space Environment Simulator, Facility 290*, NSI-26-01-198,

2. *Systems Analysis for the Vacuum and Cryogenic Systems*, F. J. Stokes corporation, Philadelphia, PA, and CryoVac, Inc. Columbus, OH; NASA contract No. 5-1333

3. *Preliminary Design Report for the Modification of the Facility 290 Thermal System*, A. Webb and J. Sushon, NSI Technology Services Corporation, NSI-26-09-280, August, 1996.

4. *Fatigue Induced Cracking in Aluminum LN2 Shroud of 39-Foot Vacuum Chamber,* Arthur E. Edwards, Ford Aerospace and Communication Corporation, Palo Alto, CA. Presented at the 13th Space Simulation Conference by Institute of Environmental Sciences; Orlando, FL, 1984.

Figure 1. The Space Simulation Environment Chamber

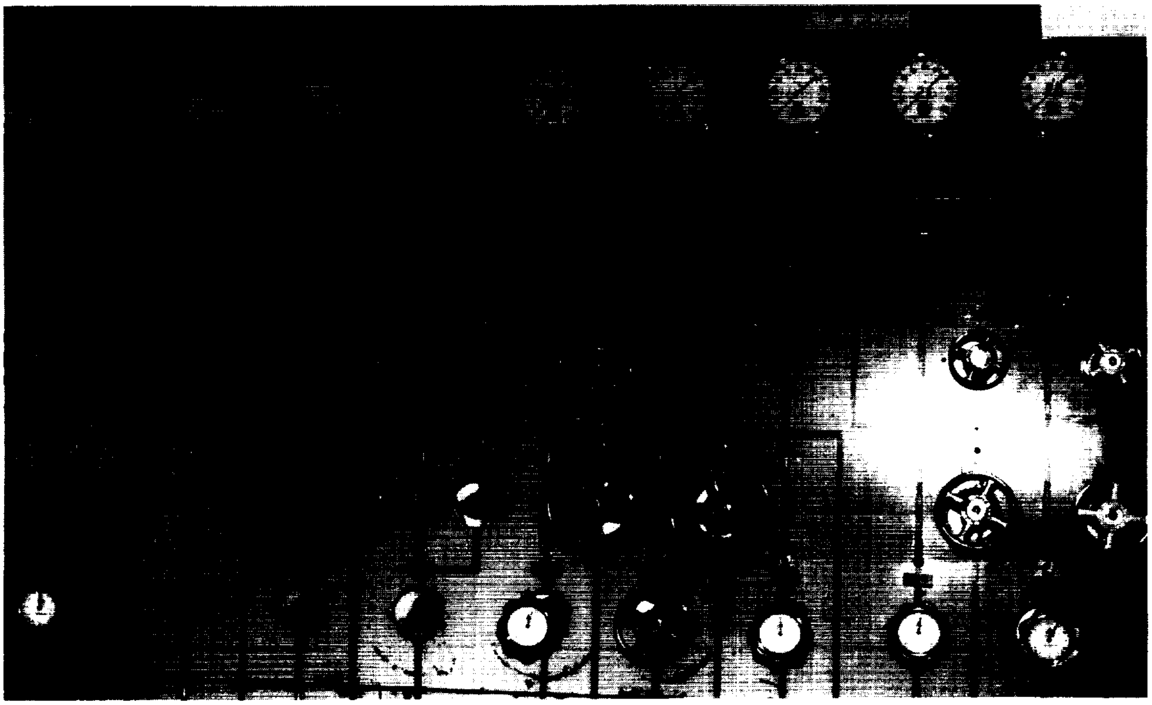

Figure 2. Typical Old Thermal System Control Panel with Manual Valves

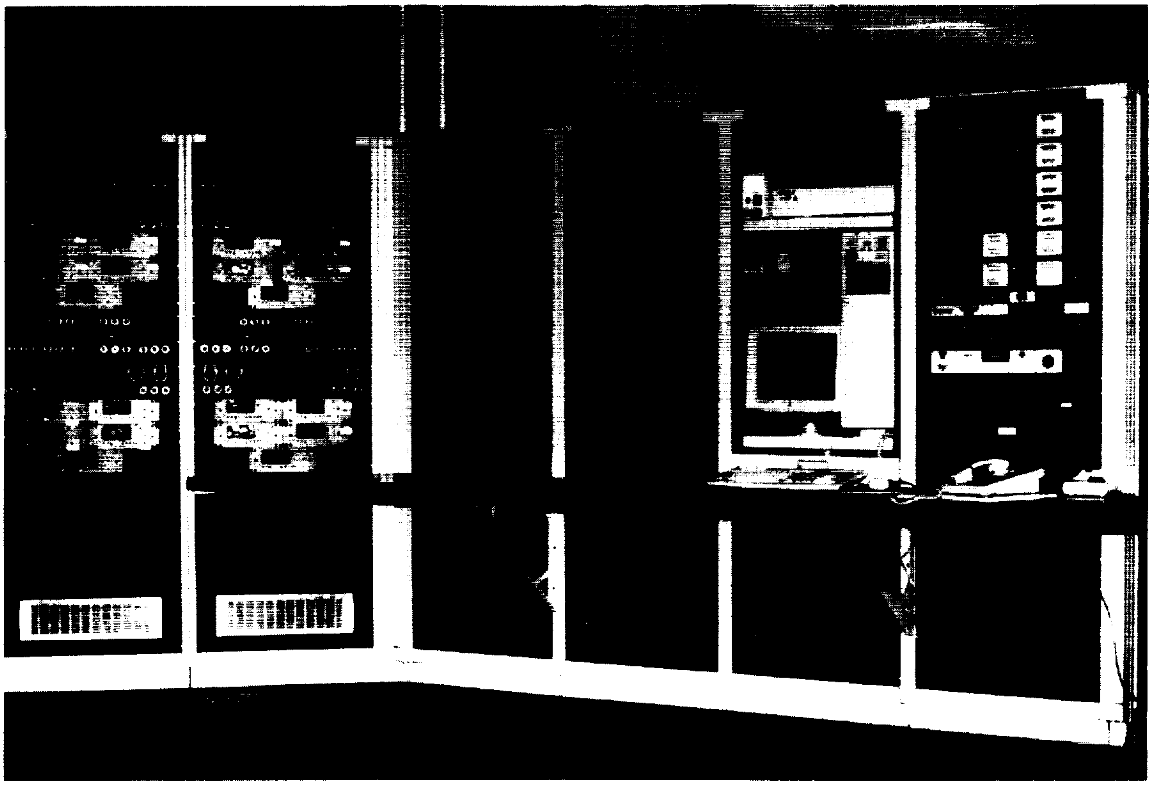

Figure 3. New PLC Based Vacuum System Control Panel

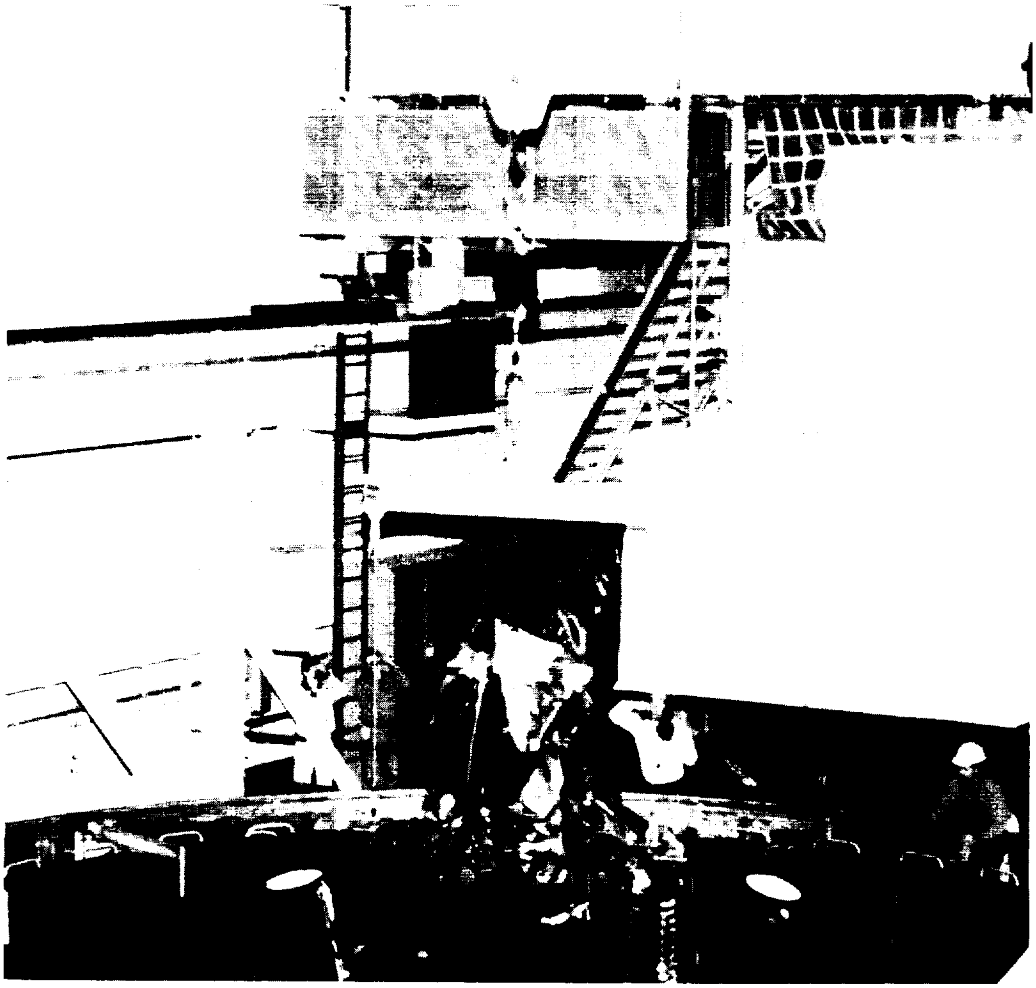

Figure 4. Side Shroud Panels with Integral GN_2 Tubes

Fig. 5. Strain Measurements Under Thermal Cycling

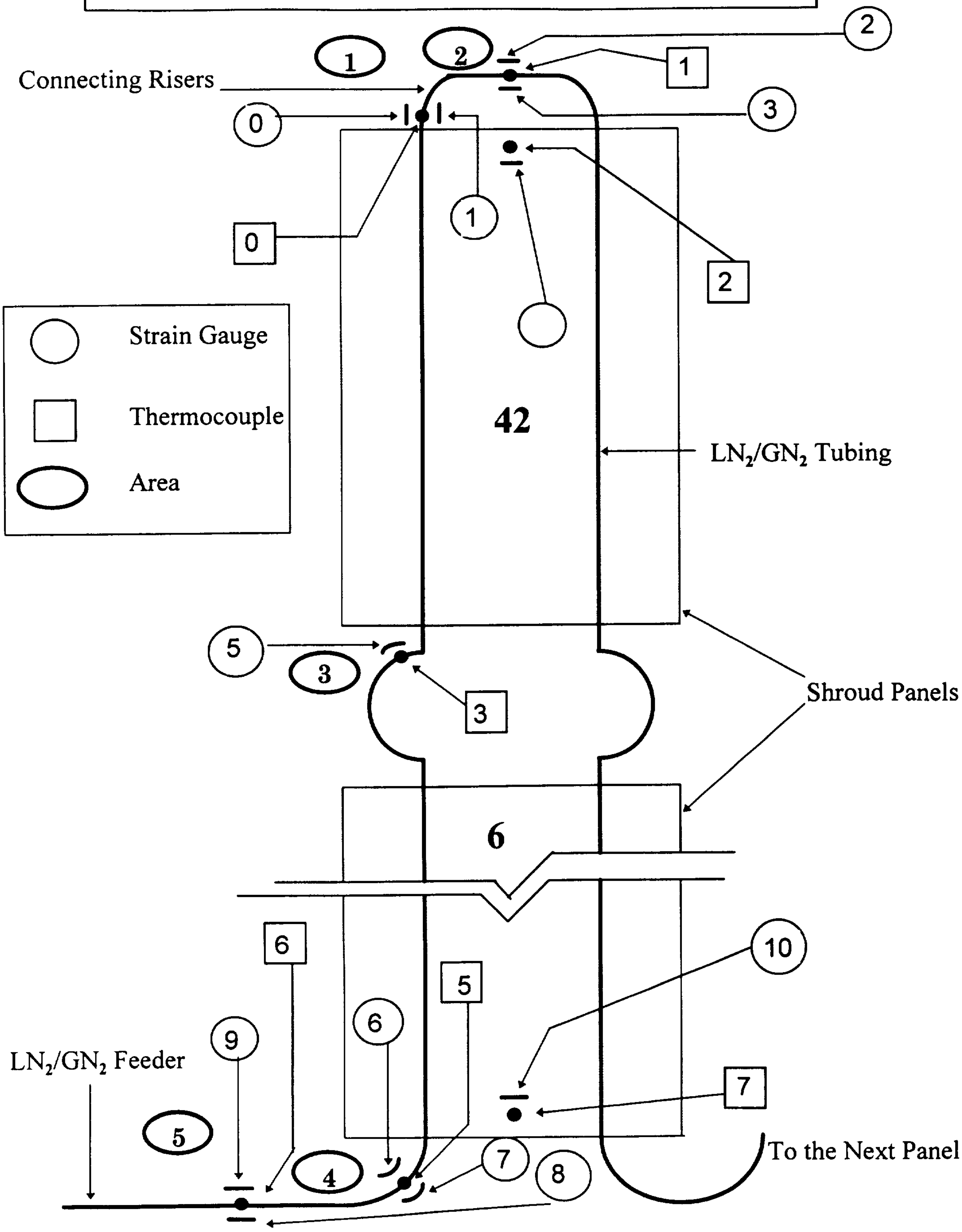

Fig. 6. Strain Under Thermal Cycling: Area 1

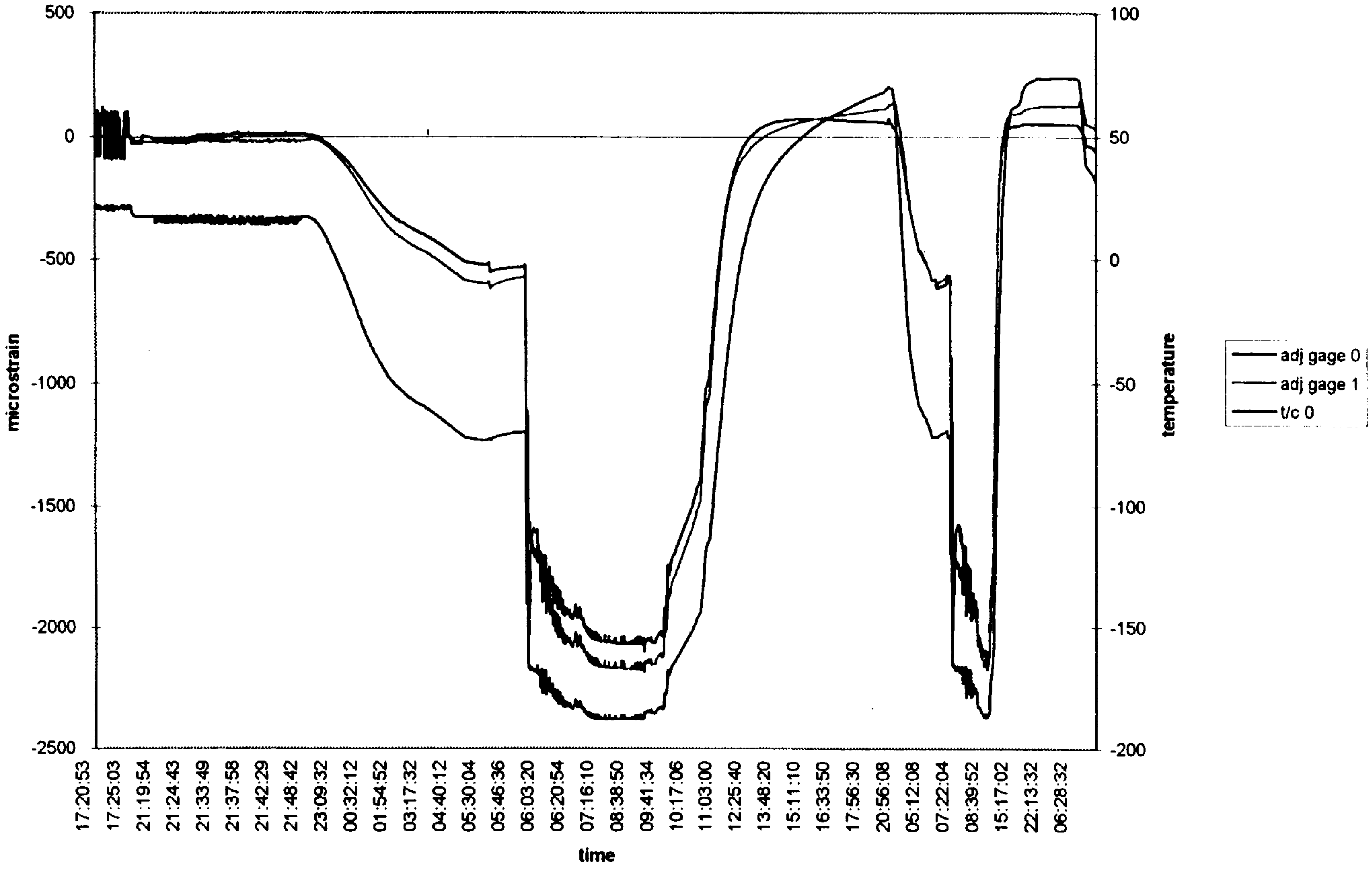

Fig. 7. Strain Under Thermal Cycling: Area 3

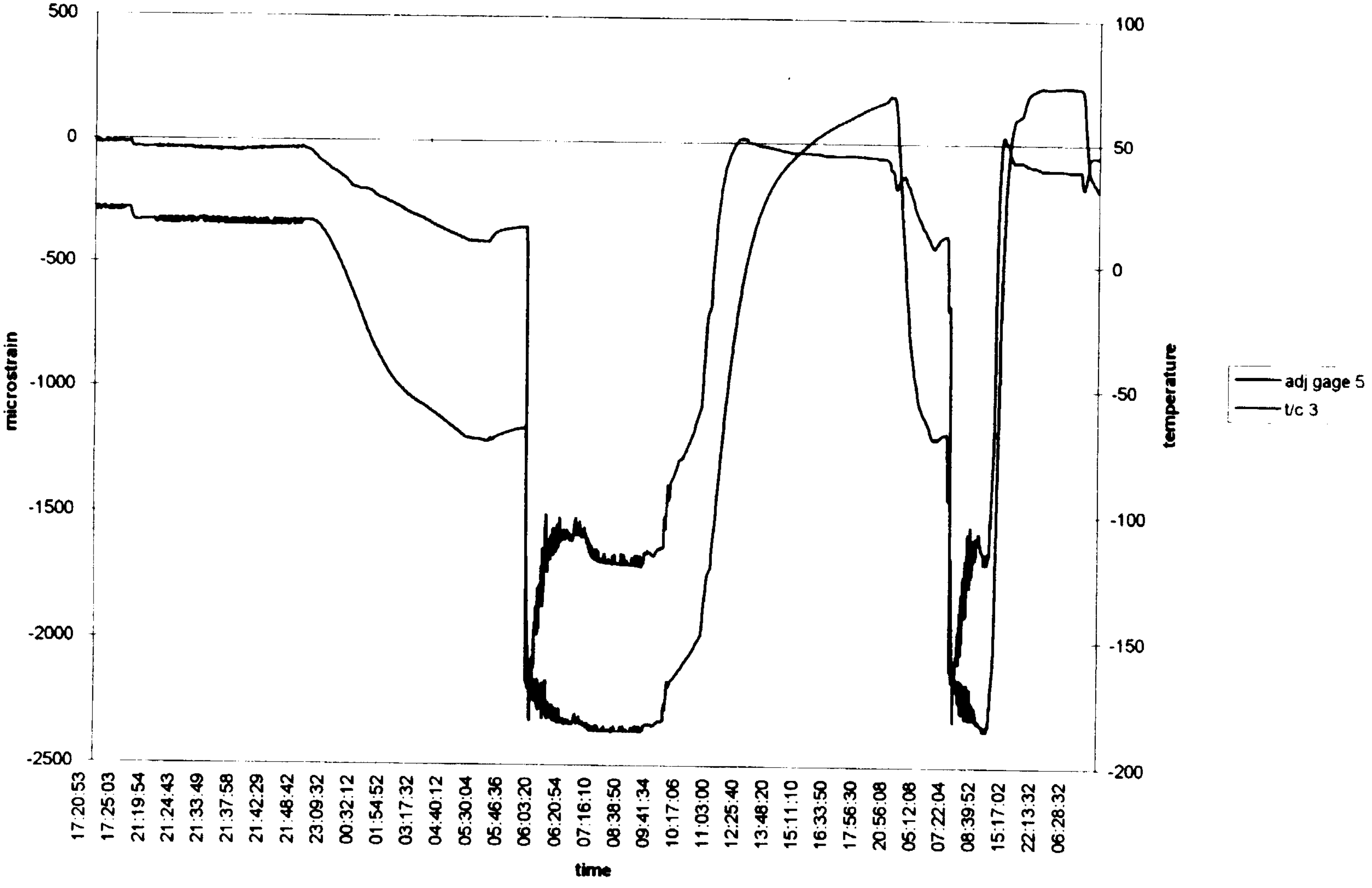

Fig. 8. Strain Under Thermal Cycling: Area 4

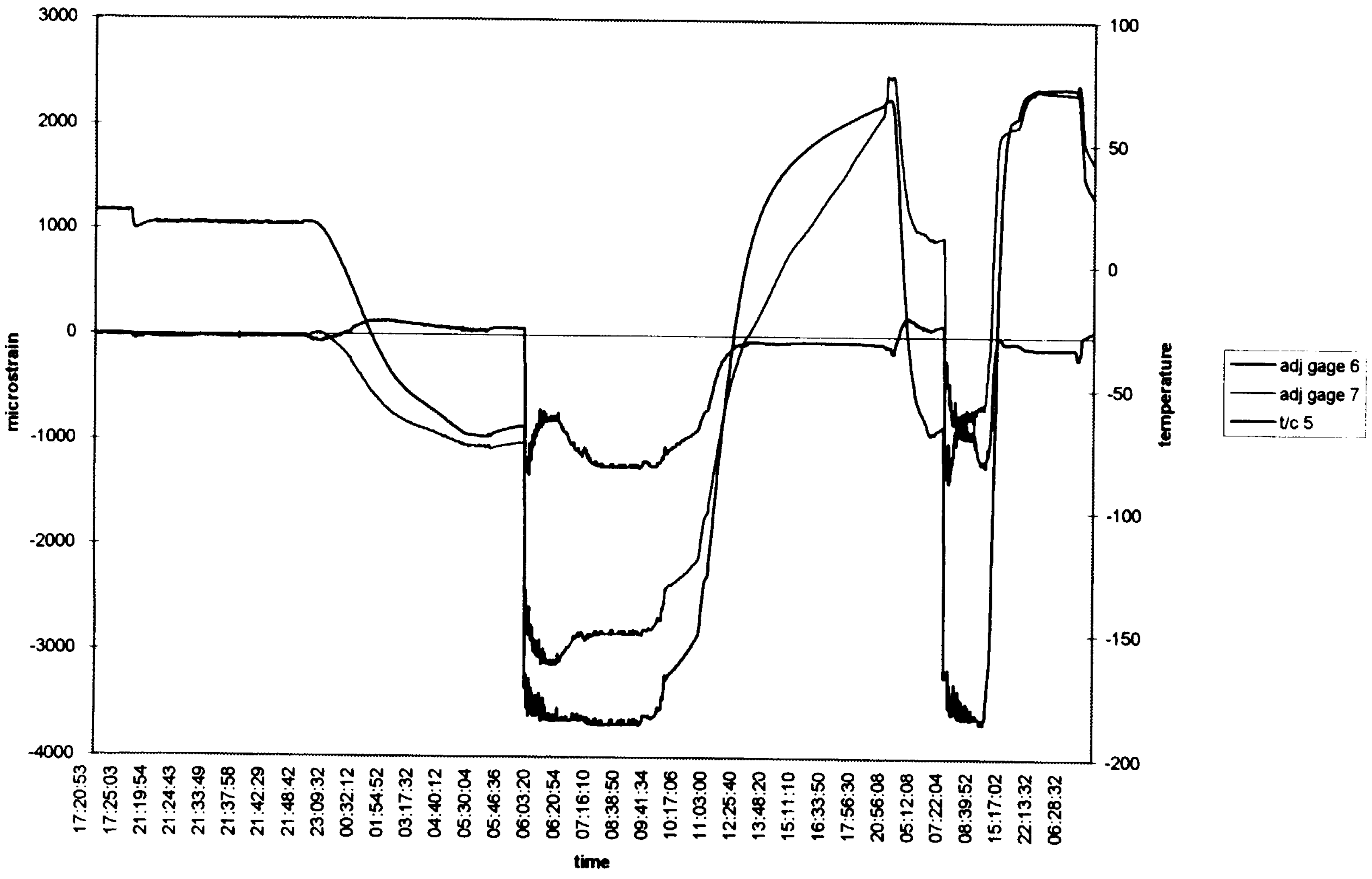

Figure 9. Weld Joint Sample with Crack

Figure 10. Crack Propagation along the Weld Joint

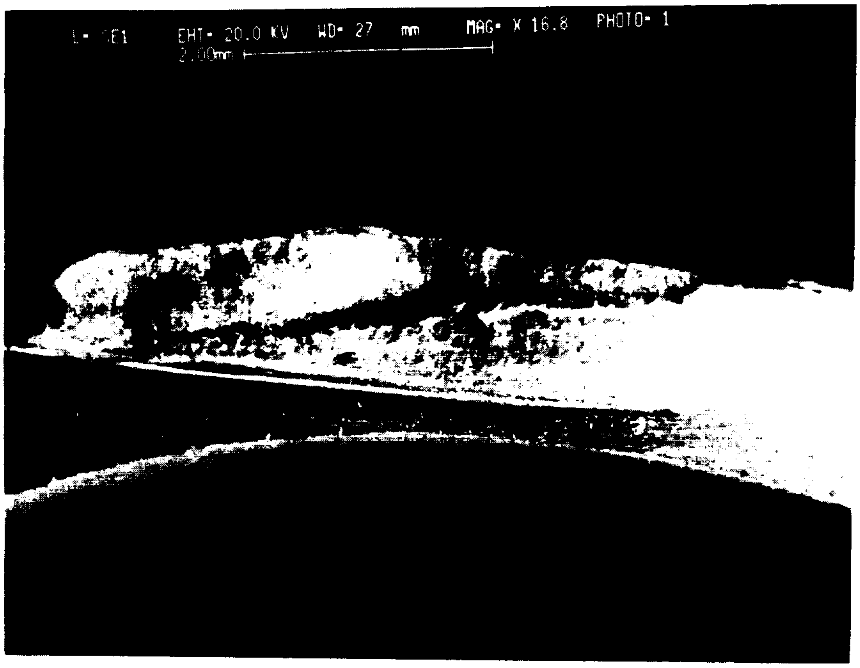

Figure 11. Width of the Developed Crack

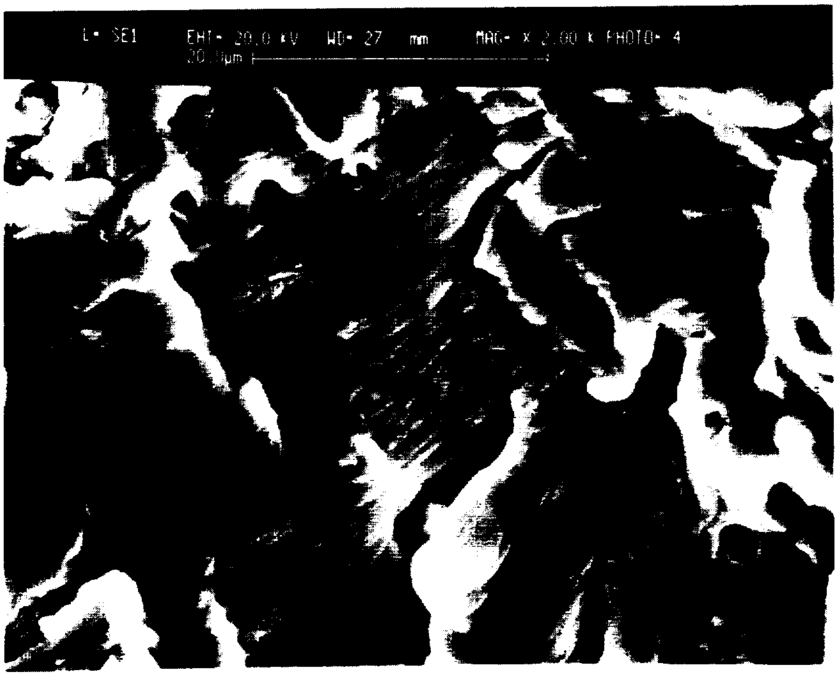

Figure 12. Accumulated Effects of the Fatigue Cycles