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To cite this article: M C A Naidu et al 2012 J. Phys.: Conf. Ser. 390 012008

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Open loop, auto reversing liquid nitrogen circulation thermal system for thermo vacuum chamber

M.C.A.Naidu, Dinesh Nolakha, B S Saharkar, KM Kavani, D R Patel

Space Applications Centre, ISRO, Ahmedabad-380 015

E-mail: mcanaidu@sac.isro.gov.in

Abstract: In a thermo vacuum chamber, attaining and controlling low and high temperatures (-100 Deg. C to +120 Deg. C) is a very important task. This paper describes the development of "Open loop, auto reversing liquid nitrogen based thermal system". System specifications, features, open loop auto reversing system, liquid nitrogen flow paths etc. are discussed in this paper. This thermal system consists of solenoid operated cryogenic valves, double embossed thermal plate (shroud), heating elements, temperature sensors and PLC. Bulky items like blowers, heating chambers, liquid nitrogen injection chambers, huge pipe lines and valves were not used. This entire thermal system is very simple to operate and PLC based, fully auto system with auto tuned to given set temperatures. This system requires a very nominal amount of liquid nitrogen (approx. 80 liters / hour) while conducting thermo vacuum tests. This system was integrated to 1.2m dia thermo vacuum chamber, as a part of its augmentation, to conduct extreme temperature cycling tests on passive antenna reflectors of satellites.

1. Introduction

As a part of augmentation of existing 1.2m dia thermo vacuum chamber, which is about 35 years old, to conduct extreme temperature cycling tests on passive antenna reflectors up to 0.9m dia, this thermal system was developed, integrated and tested successfully. Also, this system is used for active sub-system (with power dissipation) testing. Existing twin lobe compressor based gaseous nitrogen type thermal system was replaced by the proposed system. Liquid nitrogen was used for cooling and IR lamps were used for heating the panel.

Even though the entire vacuum, thermal and control systems were augmented, this paper discusses only thermal system part applicable to shroud. Auto reversing system was implemented as the required temperature gradient (\pm 7.5 K) on shroud was not obtained in one-way open loop system (\pm 16 K). Some advantages of this system are: (i) It occupies less space, as there are only two pipe lines one, vacuum jacketed (25NB inner pipe) line as inlet line and another one, armaflex insulated (25 NB pipe) line as outlet, on the ground (ii) Operation of the system is silent, as there are no noise making blowers (iii) Low power consumption (4.5 KW) (iv) Nominal liquid nitrogen consumption (approx. 80 liters/hour) etc.

2. System details

Schematic of open loop auto reversing thermal system with liquid nitrogen flow path is shown in fig. 1. Thermal panel means double embossed panel (shroud). Size of the developed view of the panel is 2420 mm X 1080 mm. The panel is in "D" shape. There are four solenoid operated cryogenic valves (CV). Nine numbers of IR lamps were distributed on the shroud. IR lamps are given power through solid state relays. Cryogenic valves are controlled by set point of temperature sensors (PT100) located at inlets of the shroud. IR lamps are controlled by set points of respective temperature sensors. Entire operation and logic is fully auto mode with PID loops and PLC based, with an option to switch on to manual mode. Shroud has two inlets and one outlet. Inlets are at the bottom and outlet at the top. In auto reversing mode inlets become outlets and outlet become inlet. Entire outside surface of shroud was covered with two layers of radiation shields, except at inlet / outlet areas.

2.1 The sequence of operation is as follows:



Fig.1. Schematic of open loop auto reversing thermal system

International Symposium on Vacuum Science & Technology and its Application for Accelerators IOP Publishing Journal of Physics: Conference Series **390** (2012) 012008 doi:10.1088/1742-6596/390/1/012008

Ref. Fig.1

- 2.1.1. When CV1, CV4 are open, CV2, CV3 are closed.
- 2.1.2. In reverse flow, when CV2, CV3 are open, CV1, CV4 are closed.
- 2.1.3. The set point temperature of temperature sensor at respective inlets (PT8, 11, 14) in fig.1 will control the ON/OFF operation of CV1, CV4 or CV2, CV3.
- 2.1.4. During the initial cooling cycle, liquid nitrogen will flow from bottom inlets (Near PT8, 14).
- 2.1.5. The temperature difference between inlet and outlet is set as a differential set point.
- 2.1.6. Liquid nitrogen will flow from the bottom inlets, till a differential set point is reached.
- 2.1.7. Then the liquid nitrogen will flow from top inlet (Near PT11), as a reverse flow.
- 2.1.8. This way the operation of valves takes place till the set temperature is reached.
- 2.1.9. Once the set point temperature is reached, the valves remain closed for few minutes.
- 2.1.10. To maintain the set temperature, frequent on / off of valves will take place.
- 2.1.11. During off condition of valves, the liquid nitrogen in the pipe lines gets warmed up and become gas.
- 2.1.12. At this time, if any valve opens, gaseous nitrogen will flow inside the shroud and disturb the temperature.
- 2.1.13. To avoid this, auto flushing system is incorporated. The gas will be flushed out automatically for 10 seconds and then start the operation of inlet valve. This is electronically incorporated.
- 2.1.14. To maintain the temperature gradient (+/-7.5 Deg. C as specification) on shroud, IR lamps will be occasionally "ON" with variable power input.
- 2.1.15. It was observed that the IR lamps were not operated during -100 deg. C steady state.
- 2.1.16. First, to go to auto mode, auto mode is to be activated by pressing a dedicated switch.
- 2.1.17. In auto mode operation, PID loops will take care of opening and closing liquid nitrogen valves and IR lamps according to their given set points.
- 2.1.18. In case, manual mode to be activated the dedicated switches for liquid nitrogen valves for top entry, bottom entry and IR lamps, to be pressed.
- 2.1.19. In manual mode, all IR lamps can be controlled by manually entering the percentage value. Refer fig. 2 & 3.

3. Instrumentation and control

Instrumentation and control system consists of a dedicated PLC, PID controller, Temperature sensors, solenoid operated liquid nitrogen valves and IR lamps. In PLC program, proportional derivative integral control logic is developed. Temperature sensors reading is fed as input to PID, PID output is sent to solenoid operated liquid nitrogen valves through contactors.

IR lamps are controlled with individual temperature sensors through SSRs..

Fig.2 shows, the "ON /OFF" status of liquid nitrogen valves and IR lamps along with % power of IR lamps.

Fig.3 shows, parameters for manual mode of operation.

PLC (Micrologix 1200 base module with 14 DI / 10 DO) with: a) 12 channel RTD input module, b) 12 channel analogue output module, c) 6 channel digital output modules was added to existing PLC (Allen Bradley) which is used for vacuum system operation and temperature data monitoring of device under test.



Fig.2. Operation status of valves and IR lamps

IN the new automation	CONTRO	ЪГ	TEM	ΙP	17	:14:09
RTD IR1	6.9	SSR	IR1	-	F3	100.0
RTD IR2	12.2	SSR	IR2	-	F4	0.0
RTD IR3	31.5	SSR	IR3	-	F5	0.0
RTD IR4	31.2	SSR	IR4		F6	0.0
RTD IR5	54.9	SSR	IR5	-	F9	0.0
RTD IR6	22.5	SSR	IR6		F10	0.0
RTD TF1	-32.0	SSR	TF1	-	F11	0.0
RTD TF2	-23.8	SSR	TF2	-	F12	0.0
RTD TF3	-4.7	SSR	TF3	-	F13	0.0
RTD TF4	-15.3	SSR	TF4	-	F14	0.0
RTD TF5	-13.9	SSR	TF5	-	F15	0.0
RTD TF6	-4.6	SSR	TF6	-	F16	0.0
<					F7 AUTO	

Fig.3. Manual mode operation screen

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4. Tests and results

Acceptance test document was prepared. Prior to acceptance test, experiments were carried out to know:

- 4.1 The variation of temperature along the length of bottom inlets by placing 5 temperature sensors in the same line,
- 4.2 Identified the conductive sensitive locations on the shroud and obtained information on the fluid flow pattern. Ref. Fig.1.
- 4.3 Mapping of temperature profile of bottom inlet and top inlet was carried out and fixed the locations of sensors.

Temperature sensors location is shown in Fig.1. Temperature distribution on shroud is shown in Fig.4



Fig.4. Temperature distribution on shroud

Maximum gradient of +/-6.5 deg.C was achieved @ -100 deg.C, with a control accuracy of +/- 1.5 deg. C. Maximum gradient of +/- 7.5 deg.C was achieved @ +120 deg.C, with a control accuracy of +/- 1 deg. C. The test was extended to see the lowest attained temperature on shroud which was seen as -186 deg.C Subsequently, 0.8m antenna reflector made of CFRP material was tested in the same chamber. Test setup is shown in Fig. 5 and Temperature Vs Time plot is shown in Fig. 6. International Symposium on Vacuum Science & Technology and its Application for Accelerators IOP Publishing Journal of Physics: Conference Series **390** (2012) 012008 doi:10.1088/1742-6596/390/1/012008



Fig. 5. 0.8 m Antenna reflector under thermo vacuum test.



Fig.6. Temperatute (⁰C) vs Time (min.) plot for antenna reflector

Acknowledgement

The authors thank Shri R K Arora, Deputy Director, ESSA for his continuous encouragement to bring out this technical paper. The authors are also thankful to Dr. R.R Navalgund, Director, SAC for permitting to present the paper. The authors acknowledge M/S Shree Raghavendra Technical Services Pvt Ltd, Ahmedabad for realization of this system successfully.