CHAPTER 4

DESCRIPTION OF EXPERIMENTAL FACILITY
CHAPTER 4 – DESCRIPTION OF EXPERIMENTAL FACILITY

4.0 INTRODUCTION

This chapter describes the experimental setup, the various components constituting it, the electrical and instrumentation details and the experimental procedure.

4.1 SELECTION OF TYPE OF FACILITY

As discussed in Sec. 2.2.1 and 2.2.2 several types of facilities are in use for measurement of cavitation erosion damage. For the present studies the vibratory cavitation device (described in Secns. 2.2.1 (v) and 2.2.2 (v)) is selected. The reasons for selecting the vibratory device are:

(i) It generates high intensity cavitation and therefore facilitates rapid evaluation of materials with high resistance to cavitation damage.

(ii) It is simple in construction and operation. Leak tightness, which is paramount while handling hazardous liquids like sodium, can be easily achieved with this device. The vertical construction of the device permits the use of a cover gas above the sodium free surface thus making it possible to achieve leak tightness by the easier method of sealing the cover gas from the atmosphere (rather than the more difficult task of sealing liquid sodium from the atmosphere).

(iii) Testing can be done with a small inventory of liquid.

(iv) The method is codified (by ASTM G32-10) which standardizes the test procedure and permits comparison of results with published literature.
4.2 DESCRIPTION OF THE FACILITY

A facility for cavitation erosion testing of materials in liquid sodium was installed for the work.

Fig. 4.1 – Schematic of the Cavitation Erosion Test Facility
Fig. 4.2 shows the photograph of the installed facility.

The main components of the facility are (Fig. 4.1) :

(i) High Temperature Ultrasonic Cavitation (HTUC) equipment

(ii) Cavitation vessel

(iii) Dump tank

(iv) Piping

4.2.1 High Temperature Ultrasonic Cavitation (HTUC) equipment:

HTUC (Fig. 4.1 & 4.2) consists of ultrasonic generator, piezoelectric transducer, booster, horn, human machine interface (HMI), software, drive mechanism and cooling arrangement.
The ultrasonic generator works on 230 V, 50 Hz, AC power supply and delivers 20 kHz signal at the appropriate voltage and frequency to a piezoelectric (PZT) transducer through an RF cable. The piezoelectric transducer, which is mounted on a ring stand, converts the electrical energy into mechanical vibrations. The output of the PZT transducer is amplified by a booster mounted on the ring stand. An ultrasonic horn mounted to the booster amplifies the booster output. The specimen to be tested is threaded to the output end of the horn and immersed in the test liquid. Cavitation occurs at the specimen face when the horn vibrates. The HMI is used to position the horn in place, set the operating parameters and control the experiment. Software is also provided to control the operating parameters and the experiment. Both manual and auto mode operations are possible with the system. The operating parameters which can be controlled include horn positions (both horizontal and vertical), the amplitude of vibration, the cooling system temperature, experiment duration.

The rated power of the equipment is 3000 W (as per ASTM G 32, a power rating of 250 W to 1000 W is suitable). The power is selected to ensure that the amplitude of vibration remains steady when the specimen is submerged in sodium at the test temperature. The system is provided with automatic resonance and amplitude control and calibration of amplitude is done in air with a filar microscope. The amplitude of vibration of the horn can be adjusted, using the HMI or the provided software, to any value in the range of 22 μm. to 47 μm.

A pneumatic system is provided for horizontal movement of the transducer-booster-horn assembly. The vertical movement of the transducer-booster-horn assembly is achieved by means of a screw nut mechanism.

Cooling of the PZT transducer and the top of the horn is achieved by means of compressed air. Cooling of the top of the cavitation vessel and the vessel flange is achieved by
circulating thermic fluid (HYTHERM 600) through cooling jackets in the vessel and flange. The thermic fluid is cooled by means of a chiller unit of 2 TR capacity. The thermic fluid is circulated through the system by means of a gear pump of 1.2 m³/h capacity (1/5 HP). The oil pump and chiller unit is integrated with the HTUC system. The system is provided with auto ON/OFF feature to maintain the temperature of the thermic fluid.

4.2.2 Vibratory horn:

The function of the horn is to amplify the displacement of the PZT crystal. The horn is of stepped type with the diameter at its bottom end sized to suit the specimen dimension (16 mm) prescribed in ASTM G 32. The power of the ultrasonic generator is selected to ensure that the amplitude of vibration remains steady when the specimen is submerged in sodium at temperature. The material of the horn is AISI D2. The temperature of the PZT transducer is maintained near room temperature by air cooling. The length of the horn is fixed such that the PZT transducer is well away from the sodium free surface. The horn is provided with a disc of 40 mm diameter which is pressed against the O ring seal on the vessel top flange central opening thus sealing the sodium in the vessel and preventing air ingress during operation. The disc is located at a nodal point on the horn and therefore its contact with the vessel at this point does not affect the frequency of operation of the horn. The length of the horn is fixed as 1.5 times the wavelength of sound in the material of the horn. The assembly of horn and specimen is designed for longitudinal resonance at the frequency of 20 kHz. The specimen is threaded to the bottom of the horn and the horn is threaded to the bottom of the PZT converter-booster assembly.

Fig. 4.3 is the sketch of the horn. Fig. 4.4 is the chemical composition test report of the material of the horn. Fig. 4.5 is the longitudinal resonance frequency test report of the horn.
Fig. 4.3 – Ultrasonic Horn

NOTE:
ALL DIMENSIONS ARE IN mm
Fig. 4.4 – Horn chemical composition test report
Roop Telsonic Ultrasonix Ltd.

FINAL PERFORMANCE & TEST REPORT (SYSTEM INTEGRATION & APPLICATION DEPT.)

HORN TEST REPORT

GENERATOR: SG-22-3KW  20 KHZ
CONVERTOR: SE-60/60-420 KHZ
BOOSTER: 1.0, 200KHZ
PARTY: IGAR
DATE: 25/6/2013
JG SHEET NC

HORN NO.  CODE NO.
Required frequency  20 KHZ  Material  D2

TESTING DETAILS

<table>
<thead>
<tr>
<th>Frequency</th>
<th>HORN NO.</th>
<th>AMP</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>20,000 KHZ</td>
<td>20 nécessity 031</td>
<td>LOSS</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>1%</td>
</tr>
<tr>
<td>ZINC Plating</td>
<td>YES</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

HORN Accepted: YES
Tested by: HARDIK PATEL
Verified by: HITESH PATEL

Fig. 4.5 – Horn longitudinal resonance frequency test report

The amplitude of vibration at the tip of the horn was measured in air is calibrated in-situ using a filament microscope as given in XI.2 of ASTM G32-10. Marcel Aubert filament microscope with RM-12 reticle having least count of 10 μm was used to measure the peak to peak amplitude of vibration. This value was measured to be 50 μm in air at room temperature.

The peak to peak amplitude of displacement employed for the present tests, however, is 25 μm. Although the recommended peak to peak displacement amplitude, as per ASTM G32-10
is 50 µm, an alternate value of 25 µm is also permitted (clause 9.1.2 of ASTM G 32-10). This value was selected because of loosening of the specimen and breakage of the horn during high temperature trials with peak to peak amplitude of 50 µm.

4.2.3 Cavitation vessel (Fig. 4.6): The cavitation vessel is of 168.3 mm outer diameter, 260 mm in height and of 7.1 mm thickness. It is made from 6” schedule 40S pipe of ASTMA312 grade 316LN material. The vessel is provided with bottom inlet and outlet nozzles and two side nozzles that serve as overflow nozzles. The vessel is provided with a ring flange which rests on the support structure. The top of the vessel is closed with a top flange that is bolted to the ring flange. Leak tightness between the two flanges is achieved by means of O ring seal provided on the ring flange. Cooling jackets are provided at the vessel top and on the top flange. Thermic fluid is circulated through these jackets during operation to remove the heat transferred from the hot liquid sodium in the vessel to the top flange. This arrangement is necessary to maintain the temperature of the horn within limits during operation. The top flange is also provided with a central opening through which the horn containing the test specimen is introduced into the vessel. O ring seal is provided on the top surface of the opening to provide leak tightness between this surface and the horn. The central opening is closed with a blind flange, bolted to it, when the system is not in operation. The top flange is provided with nozzle openings for the introduction of level probes and cover gas connection. Nozzle openings are also provided to the cooling jackets for entry and exit of cooling thermo fluid oil. The bottom surface of the top flange is provided with thermal baffles for reducing the heat load from liquid sodium to the flange. The thermal baffles are supported on tie rods which are screwed to the bottom of the top flange.
The vessel is provided with two spark plug type level probes, viz. low level probe and high level probe, to maintain the submergence of the specimen to the desired level.

During operation the vessel is filled with sodium up to the high level indication and the sodium free surface is topped by argon cover gas. The cover gas in the vessel is connected to the common cover gas header through a vapor trap.

Although separate nozzles are provided at the vessel bottom for inlet and outlet, only one nozzle is used and the other is dummyed and kept as spare nozzle. The inlet/outlet nozzle is provided with a bellows sealed valve to isolate the cavitation vessel and maintain the sodium level in the vessel during the experiment.

4.2.4 Dump tank: The dump tank (Fig. 4.7) is located at the bottom most part of the circuit. The tank is made from SS 316LN grade material. It contains enough sodium to fill the cavitation vessel to the required capacity. The cavitation vessel is emptied into the dump tank after each experiment is completed. The dump tank is provided with two spark plug type level probes. The sodium in the dump tank is topped by argon cover gas and the cover gas in the tank is connected to the common cover gas header through a vapor trap.

4.2.5 Piping: SS 316LN piping (1/2” sch 40 ) is used to connect the dump tank to the cavitation vessel. Adequate flexibility is provided in the piping through expansion bends
Fig. 4.6 – Cavitation Vessel
4.2.6 Electrical And Instrumentation Details

The cavitation vessel, dump tank and interconnecting pipeline are provided with high temperature tape heaters for preheating the vessel and heating sodium in the vessel.

Table 4.1 gives the heater details.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Heater</th>
<th>Rating</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>H1</td>
<td>2 m / 400 W</td>
<td>Cavitation vessel</td>
</tr>
<tr>
<td>2</td>
<td>H2</td>
<td>5 m / 1000 W</td>
<td>Sodium piping</td>
</tr>
<tr>
<td>3</td>
<td>H3</td>
<td>2 m / 400 W</td>
<td>Dump tank</td>
</tr>
<tr>
<td>4</td>
<td>H4</td>
<td>2 m / 400 W</td>
<td>Dump tank</td>
</tr>
<tr>
<td>5</td>
<td>H5</td>
<td>2 m / 400 W</td>
<td>Vapor trap of dump tank</td>
</tr>
<tr>
<td>6</td>
<td>H6</td>
<td>2 m / 400 W</td>
<td>Vapor trap of cavitation vessel</td>
</tr>
<tr>
<td>7</td>
<td>H7</td>
<td>3 m / 600 W</td>
<td>Sodium sampler line</td>
</tr>
</tbody>
</table>
Power supply to the heaters is provided through triac based power control units. Heating system is divided into 4 zones. Zone-1 consists of cavitation vessel heater (H1), zone-2 consists of sodium pipe line heater (H2), zone-3 consists of dump tank heaters (H3) and (H4), zone 4 consists of heaters (H5) of vapor trap of dump tank, zone-5 consists of heaters (H6) of vapor trap of cavitation vessel, and zone-6 consists of heater (H7) in sodium sampler line.

Eleven K type thermocouples are provided for temperature measurement at different locations. The temperature of the sodium in the vessel is monitored using 2 nos. of thermocouples located at 50 mm and 150 mm from the vessel bottom.

The cavitation vessel is provided with 2 nos. of spark plug type level probes for level measurement. The elevation difference between the low level probe and the high level probe is 12 mm. Fig. 4.8 indicates the low level and high level of sodium in the vessel vis-à-vis the face of the specimen during testing.

The instruments used to measure the test parameters are given in Table 4.2 below

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Parameter</th>
<th>Instrument</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Weight</td>
<td>Electronic balance</td>
<td>± 0.1 mg</td>
</tr>
<tr>
<td>2</td>
<td>Time</td>
<td>Stop watch</td>
<td>± 1 s</td>
</tr>
<tr>
<td>3</td>
<td>Cover gas pressure</td>
<td>Bourdon gage</td>
<td>± 10 mbar</td>
</tr>
<tr>
<td>4</td>
<td>Level of sodium</td>
<td>Resistance type level probe</td>
<td>± 1 mm</td>
</tr>
<tr>
<td>5</td>
<td>Temperature</td>
<td>K type thermocouple</td>
<td>± 1.5% of reading</td>
</tr>
<tr>
<td>6</td>
<td>Ultrasonic operating frequency</td>
<td>Automatic control in HTUC</td>
<td>± 0.5 kHz</td>
</tr>
<tr>
<td>7</td>
<td>Displacement amplitude</td>
<td>Automatic control in HTUC</td>
<td>± 2.5 μm</td>
</tr>
</tbody>
</table>
Fig. 4.8 – Sodium levels and specimen during testing
The bottom surface of the specimen is submerged by 12 mm when the high level indication is live. This ensures that the submergence of the specimen during testing is in conformance with the submergence requirement specified in ASTM G 32.

Seven leak detectors arranged in a single channel are provided for the test set up. One spark plug type leak detector is provided for valve VNa1. The output of thermocouples and leak detectors is displayed using a toggle switch operated digital indicator.

Fig.4.9 is a schematic of the facility showing heater, thermocouple and leak detector details.
Fig. 4.9 – Layout of heaters, thermocouples and leak detectors in the facility
The locations of the leak detectors and thermocouples in the set up are summarized in Table 4.3 below:

**Table 4.3 – Locations of leak detectors and thermocouples**

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Component</th>
<th>Level probe</th>
<th>Leak detector</th>
<th>Thermocouple</th>
<th>Pressure gage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cavitation vessel</td>
<td>2 nos. of spark plug type</td>
<td>1 nos. on weld between vessel shell and bottom dished end 1 nos. on weld between vessel bottom nozzle and piping</td>
<td>K type 2 nos. on vessel body 1 nos. on vessel bottom nozzle 1 nos. on vapor trap</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>Bellows sealed valve</td>
<td>---</td>
<td>1 nos. on valve body 1 nos. above bellows</td>
<td>K type 1 nos. on vessel body</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>Piping</td>
<td>---</td>
<td>---</td>
<td>K type 1 nos. in horizontal run</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>Dump tank</td>
<td>---</td>
<td>1 nos. on weld between piping and dump tank nozzle 3 nos. on dump tank surface</td>
<td>K type 3 nos. on vessel body 1 nos. on cover gas line 1 nos. on vapor trap</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>Cover gas</td>
<td></td>
<td></td>
<td>Independent Bourdon type gage on cover gas lines of dump tank and cavitation vessel.</td>
<td></td>
</tr>
</tbody>
</table>
4.3 DESIGN OF MAJOR COMPONENTS

4.3.1 Components Design

4.3.1.1 Cavitation vessel

The cavitation vessel is designed as per Boiler and Pressure Vessel code ASME Sec VIII Divison1. The design temperature is 550°C. All welds are radiographed and the vessel subjected to pneumatic testing.

4.3.1.1.1 Cooling system: Cooling jackets are provided on the top flange and the top portion of the outer surface of the cavitation vessel. Cooling is achieved by circulating thermic fluid (Hytherm 600) through the cooling jackets. The thermic fluid is cooled by an air / liquid heat exchanger and auto regulation of temperature is provided. consists of

4.3.1.2 Dump tank: The dump tank is designed as per Boiler and Pressure Vessel code ASME Sec VIII Divison1. The design temperature is 400°C. All welds are radiographed and the vessel subjected to pneumatic testing.

4.3.1.3 Ultrasonic horn: The ultrasonic horn is made of tool steel HCHC, AISI D2. The following considerations govern the selection of material of construction of the horn:

(i) fatigue strength: materials with high fatigue strength can be operated at high amplitudes (i.e. high stress levels)

(ii) low acoustic loss

(iii) compatibility with sodium

100
(iv) resistance to cavitation because a portion of the horn is immersed in the liquid and can experience high impact load from collapsing bubbles

(v) machinability

(vi) availability and cost

(vii) high yield strength, high impact strength

(viii) satisfactory mechanical properties at high operating temperature

The length of the horn is fixed as 1.5 times the wavelength of sound in the material of the horn. The assembly of horn and specimen is designed for longitudinal resonance at the frequency of 20 kHz. The horn is subjected to alternating stress during operation. The analysis of the horn to determine its longitudinal natural frequency and displacement and stress along its length is discussed in Appendix 1.

4.4 PRE-COMMISSIONING TESTS

Purified sodium was transferred to the dump tank up to high level indication. The tank was cooled, cut from the transfer system and dummied. It was then positioned in the test area and connected to the piping from the cavitation test vessel.

The horn containing the test specimen was connected to the booster, the ultrasonic generator powered and satisfactory operation of the ultrasonic system confirmed. The satisfactory operation of the pneumatic system, energizing the horizontal movement of the booster-horn assembly, and the motorized screw nut assembly, for vertical motion of the booster-horn assembly, was confirmed.

The cavitation vessel was closed with the top flange and the assembly of horn and specimen lowered in to the vessel through the central opening in the flange until the collar on the
horn rested on the O ring joint in the central opening and sealed the vessel. The bellows sealed valve at the inlet of the cavitation vessel was closed and the vessel flushed with argon. Pressure hold test of the vessel was done at 0.5 bar (g) for 4 h to confirm leak tightness. The valve was then opened, the entire system flushed with argon and pressure hold test of the entire system done at 0.5 bar(g) for 4 h.

4.5 DETAILS OF TEST SPECIMENS

Figs. 4.10, 4.11 show typical test specimens. The specimens are of ~ 16 mm in diameter. The circular specimen was provided with two diametrically opposite flats of 7.5 mm width to facilitate tightening using a standard spanner. Three types of specimens were tested. Type 1 was austenitic stainless steel (SS 316L) machined from bar stock, Type 2 was austenitic stainless steel (SS 316 L) machined from bar stock and hard faced with Colmonoy5 and Type 3 was austenitic stainless steel (SS 316 L) machined from bar stock and hard faced with Stellite6. The tests were done in sodium at temperatures of 200°C, 250°C, 300°C and 400°C. At 200 °C, three nos. of SS 316L specimens , two nos. each of Colmonoy5 hardfaced specimens and Stellite6 hardfaced specimens were tested; at 250°C, two nos. of SS 316L specimens, three nos. of Colmonoy5 hardfaced specimens and two nos. of Stellite6 hardfaced specimens were tested; at 300°C, three nos. of SS 316L specimens , two nos. of Colmonoy5 hardfaced specimens and one no. of Stellite6 hardfaced specimens were tested; and at 400°C one nos. each of SS 316L, Colmonoy5and Stellite6 hardfaced specimens were tested.
The chemical composition of the base metal of the specimens (SS 316 L) specimens tested is shown in Table 1 (by direct reading optical emission spectrometer) [108].
4.6 PREPARATION OF SPECIMENS

The specimens were machined from SS316L, 20 mm bar stock. The circular specimen was provided with two diametrically opposite flats of 7.5 mm width to facilitate tightening using a standard spanner. The face of the specimen was polished to mirror finish (< 1 μm for SS316L and Stellite6 specimens and ~ 2.5 μm for Colmonoy5 specimen) so as to enable meaningful examination of the test surface (by SEM) after short duration tests. Hardness of the specimens was measured, before polishing, by selecting randomly 2 pieces from lots of ~ 15 samples. The measured hardness and other properties of the samples are shown in Table 4.5.

Table 4.5 – Properties and measured hardness of hard faced deposits

<table>
<thead>
<tr>
<th>Properties</th>
<th>SS 316 L</th>
<th>Hardfacing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stellite 6</td>
<td>Colmonoy5</td>
</tr>
<tr>
<td>Deposit thickness, mm (average)</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Density, g/m³</td>
<td>7.97 [109]</td>
<td>8.12 [110]</td>
</tr>
<tr>
<td>Hardness, Maximum value</td>
<td>96.4 HRB [112]</td>
<td>39.4 HRC [112]</td>
</tr>
<tr>
<td>Mean + SD (measured from 2 random samples in each type using FIE, model RASNE-1 digital Rockwell hardness tester)</td>
<td>95.61 ± 0.77 HRB (233 VHN)</td>
<td>38.64 ± 0.67 (369 VHN)</td>
</tr>
</tbody>
</table>

Typical compositions of the hard facing deposits, Colmonoy5 and Stellite6, are given in Table 4.6. Both materials were deposited in powder form by Plasma Transfer Arc Welding
(PTAW) process. Established welding procedure specification was used for deposition of the hardfacing coating [113].

**Table 4.6 - Typical compositions of Colmonoy5 and Stellite6 [18]**

<table>
<thead>
<tr>
<th>Alloy</th>
<th>B</th>
<th>C</th>
<th>Cr</th>
<th>Co</th>
<th>Fe</th>
<th>Mn</th>
<th>Ni</th>
<th>Si</th>
<th>W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stellite 6</td>
<td>-</td>
<td>1.0</td>
<td>27.0</td>
<td>60</td>
<td>&lt; 2.5</td>
<td>1.0</td>
<td>&lt; 2.5</td>
<td>1.0</td>
<td>5</td>
</tr>
<tr>
<td>Colmonoy5</td>
<td>2.5</td>
<td>0.65</td>
<td>11.5</td>
<td>&lt; 0.25</td>
<td>4.25</td>
<td>-</td>
<td>77.10</td>
<td>3.75</td>
<td>-</td>
</tr>
</tbody>
</table>

4.7 **SODIUM PURITY**

The impurity levels present in the initial charge of sodium are:

\[ O = 5 \text{ ppm}, \; C = < 5 \text{ ppm}, \; Ca = < 2 \text{ ppm}, \; B < 1 \text{ ppm}, \; Ba < 7 \text{ ppm}, \; Li < 0.2 \text{ ppm}, \; Fe < 0.5 \text{ ppm}, \; Zn < 2 \text{ ppm}, \; U < 0.001 \text{ ppm}, \; K < 250 \text{ ppm}, \; Ag < 0.5 \text{ ppm}, \; S < 10 \text{ ppm}, \; Cl < 10 \text{ ppm}, \; Br < 5 \text{ ppm}. \] [114]

The system does not have a built in purification facility. However, the cover gas pressure in the system was maintained above atmospheric pressure, both during operation and when not in use, to prevent air ingress. Also, during interventions to introduce or remove the horn/specimen from the system, continuous argon purging was maintained to prevent air ingress. Although care was taken through operational procedures to maintain inert atmosphere in the facility, it was observed after several experiments (~ 50 nos.) that the impurity level in the system had increased. It is reported [22, 24] that oxygen level of 100 ppm in sodium does not have adverse effect on resistance to cavitation erosion in stainless steel. In this case the maximum expected oxygen impurity at the highest temperature operated (300°C), assuming saturation conditions, is 100 ppm.
After the initial tests at 300°C, the sodium in the facility was replaced with fresh charge of sodium for further tests. The dump tank in the facility was cut and removed and replaced with a new dump tank containing purified sodium. Care was taken during the experiments to maintain the purity by argon purging during system interventions and by ensuring positive cover gas pressure during operation as well as when the system was not in use.

4.8 OPERATING PARAMETERS

The following are the operating parameters for all experiments:

Frequency of operation : 20 kHz

Amplitude of operation (peak to peak) : 25μm

Power of ultrasonic generator : 3000 W

Submergence of specimen = 11 mm

Pressure of argon cover gas in cavitation vessel = 100 mbar(g).

4.9 EXPERIMENTAL PROCEDURE

The specimen is polished, cleaned using water and then with acetone, dried and weighed using an electronic balance of 0.1 mg accuracy. In the case of specimens which are to be examined by SEM during the course of the testing, the specimens are examined by SEM before the test. The specimen is assembled on the ultrasonic horn and the assembly mounted on the vibratory cavitation equipment.

Before starting the experiment, the system is checked for leak tightness by a pressure hold test. This is followed by cold purging of the entire system to expel any residual moisture. The system is then preheated and the cavitation vessel purged with argon in hot condition. The
ultrasonic horn containing the test specimen is then introduced into the cavitation test vessel with continuous argon purging to prevent air ingress. The cavitation test vessel is then filled with sodium to the required level by pressurizing the dump tank and venting the cavitation test vessel. The level of sodium in the cavitation test vessel is monitored using two nos. of resistance type level probes.

After filling, the cavitation test vessel is isolated from the dump tank. The temperature of sodium in the cavitation test vessel is then stabilized to the test temperature after which the ultrasonic horn is powered to start the experiment. The duration of a single test varies from as low as 5 min (in cases where SEM examination is planned) to as long as 2 hours.

After the prescribed test period, the ultrasonic horn is switched off, sodium dumped and the cavitation test vessel cooled to room temperature. The horn is then removed from the vessel under continuous argon purging and sealed in polythene bag in argon atmosphere (Fig. 4.12). The central opening of the cavitation test vessel is closed and both the cavitation test vessel and the dump tank are maintained under inert atmosphere to prevent any air ingress into the system.
The specimen is then removed from the ultrasonic horn, cleaned first with methyl alcohol and then in ultrasonic bath with distilled water. Care is taken to ensure that the cleaning process does not result in any erosion of the specimen by locating the specimen away from the base of the bath, where the transducers are fixed, and by suspending the specimen in the bath such that its face is away from the transducers in the bath. The specimen is then cleaned and dried.

4.10 MEASUREMENTS AND EXAMINATION AFTER TESTING

The specimen is well polished to mirror finish, cleaned and dried and weighed. Prior to start of the test the hardness of each type of specimen is measured from 2 random samples in each type using FIE, model RASNE-1 digital Rockwell hardness tester. One or two samples
(which are selected for SEM examination and roughness measurements during the course of testing) are examined using SEM before start of testing. The surface roughness before start of testing is also measured for the selected specimens using optical profilometer.

4.10.1 Weight loss measurement

The cleaned and dried specimen is weighed using an electronic balance with accuracy of 0.1 mg. The weight loss incurred in the test is estimated and the cumulative weight loss calculated. The testing time of the particular test and the cumulative testing time are also recorded.

If \( W_0 \) is the initial weight of the cavitation free specimen specimen, \( W_i \) is the weight after the \( i \)th test and \( t_i \) is the time duration of the \( i \)th test, then the cumulative weight loss is given by \( \Delta W = W_0 - W_i \) and the cumulative time is \( \sum t_i \). The cumulative weight loss rate, \( \Delta W' = \Delta W / \sum t_i \),

4.10.2 SEM examination

Selected specimens are examined under a scanning electron microscope (using Obducat Camscan-3200 SEM) at various magnifications at different locations in the periphery and the central region.

4.10.3 Roughness measurement

The roughness of select few specimens after each test was measured with the objective of correlating surface roughness with cavitation damage due to weight loss. Surface roughness of the selected specimens was measured using a non-contact type optical profiler Talysurf CLI 1000. Rectangular areas, in the middle of the specimen, of dimensions 2 mm * 10 mm and 2 mm * 13 mm, in mutually perpendicular directions (x and y), were scanned. The average roughness, \( R_a \), was computed from the scanned data. The average roughness, \( R_a \), is defined as the
arithmetic mean deviation of the surface. It is the roughness height as calculated over the entire measured area in each of the directions, x and y. The absolute roughness is then calculated as the square root of the sum of the squares of the average roughness in the x and y directions.