DETECTION OF STEAM LEAKS INTO SODIUM IN FAST REACTOR STEAM GENERATORS BY ACOUSTIC TECHNIQUES - AN OVERVIEW OF INDIAN PROGRAMME

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1.0 INTRODUCTION

Early detection of water or steam leaks into sodium in the steam generator units of Liquid Metal Fast Breeder Reactors (LMFBR) is an important requirement from economic and safety considerations. Realising the potential of acoustic leak detection technique, an experimental programme was initiated a few years back at Indira Gandhi Centre for Atomic Research (IGCAR) to develop this technique. The first phase of this programme consists of experiments to measure background noise characteristics on the steam generator modules of the 40 MW (thermal) Fast Breeder Test Reactor (FBTR) at Kalpakkam and experiments to establish leak noise characteristics with the help of a leak simulation set up. By subjecting the measured data from these experiments to signal analysis techniques, a criterion for acoustic leak detection for FBTR steam generator will be evolved. Second phase of this programme will be devoted to developing an acoustic leak detection system suitable for installation in the 500 MWe Prototype Fast Breeder Reactor (PFBR).

This paper discusses the first phase of the experimental programme, results obtained from measurements carried out on FBTR steam generators and results obtained from leak simulation experiments. Acoustic leak detection system being considered for PFBR will also be briefly described.

2.0 EXPERIMENTAL PROGRAMME - FIRST PHASE

An ideal procedure for developing acoustic leak detection technique would be to simulate a leak by injecting steam or an inert gas into sodium during testing of a prototype steam generator unit and extract the leak signal from the background noise. Since this is a complicated and costly procedure, an alternate approach was evolved for developing acoustic leak detection system for use in FBTR steam generator modules. In this approach, background noise characteristics are measured on FBTR steam generator modules (Fig.1) during the commissioning phase and leak noise characteristics are measured using a simulation set up consisting of a segment of FBTR steam generator (Fig.2). For this latter experiment, high pressure argon/helium gas is injected into static water through micro sized holes simulating the defects. In order to simulate sound transmission characteristics, namely distortion and attenuation, the internal tube arrangement in the steam generator module is retained in the simulation set up also. Same transducers and mounting arrangements are used in both the experiments. Use of water in place of sodium can be justified since the values of density, sound velocity and absorption are comparable in the two media. In this simulation experiment 'combustion/flame noise' in the reaction zone which occurs during actual steam leak into sodium is not simulated. However, the two dominating mechanisms of jet noise and bubble noise are well simulated.

By comparing the signals from the two experiments, it should be possible to identify features of the leak signal which are distinguishable from the background noise and also to establish detection threshold. Suitable algorithms can be written for leak detection and tested on edited data which is created by mixing the background and leak signals obtained from the two experiments.

3.0 BACKGROUND NOISE MEASUREMENTS

3.1 <u>Installation of transducers</u>

Each of the two secondary loops in FBTR has two steam generator modules in parallel and each module is rated for 12.5 MW (thermal). It is a shell and tube once through heat exchanger of serpentine configuration (Fig.1). The steam generator modules are housed inside an insulated casing and temperature inside the casing is expected to be around 673K. It was decided to carry out measurements on two modules, one in each secondary loop.

Twenty mm diameter and 1 m long 2 1/4 Cr - 1 Mo ferritic steel wave guides were welded to the steam generator shell on the 'U' bend portions and the wave guides were extended to casing outside through suitable penetrations. This arrangement enabled installation of low temperature transducers at the cold end of the wave guide which can be replaced during experiments. Wave guides were installed on the 'U' bends because this region contains tube to tube weld zones, a likely zone of failure.

Piezoelectric accelerometers and acoustic emission sensors, which cover a wide frequency range were selected for background noise measurements. Important specifications of the transducers are given below:

	Accelerometers		A.E.Sensor
	Type-1	Type-2	
Sensitivity	45 pc/g	12 pc/g	-80dB ref. 1 volt per microbar
Mounted resonance frequency	27kHz	110kHz	-
Frequency range (3dB)	to 9kHz	to 30kHz	100-1000 kHz; flat response type
Dynamic range	2000g	2000g	-

3.2 Preliminary experiments at FBTR:

Recently sodium was filled into the steam generator modules at FBTR and it was possible to commence background noise measurements with only sodium flow. Preliminary measurements carried out at FBTR indicated that at sodium temperatures below 523K, diffusion type in-sodium hydrogen detectors installed at FBTR are not very effective in detecting a leak [1]. At low temperatures hydrogen generated tends to remain in the form of gas bubbles. Hence measurements were also carried out to check whether the acoustic transducers installed on the modules can detect gas bubbles in sodium flow. Known volumes of argon and hydrogen were injected into sodium through 20 mm inner diameter pipe at a point upstream of steam generator sodium inlet for these measurements. These were carried out at a sodium flow corresponding to a reactor power level of 10.5 MW (thermal), upto which power FBTR will be operated during the initial phase of power operation.

All the above measurements were carried out at wave guide locations ST and SM (Fig.1) using accelerometer Type-1 and the instrument schematic shown in Fig.3. All measurements were carried out over a bandwidth of 100Hz to 20kHz. Results are briefly discussed in the following sections. The two instrumented modules are identified as east module and west module, based upon their physical location in the plant.

3.3 Results

3.3.1 Sodium flow noise measurements:

As expected, the flow noise was random in nature. Fig.4 shows the power spectrum density (PSD) plots for the flow noise measured at a secondary pump speed of 410 RPM and sodium flow of 80 Cum/h in the west module. These correspond to a reactor power level of 10.5 MW(t). Flow noise was also measured at different flows between 0 and 143 Cum/h and the RMS value of the signal was found to increase with flow with an exponent of 2 to 3.

3.3.2 Gas injection measurements

Experiments were initially carried out with argon and finally with hydrogen. From argon injections, it was established that the transducers responded when the volume of argon injected was about 1.4 litres at STP (circulating sodium volume was 16 Cum) and the response was not positive at much lower volumes like 0.2 litres. Injection period could not be precisely controlled. Signal level increased due to sodium flow containing gas bubbles. Fig.4 compares the power spectrum of flow noise signal before and after argon gas injection and the overall increase in signal level can be seen.

1.4 litres of hydrogen gas was injected into sodium in the west module at sodium temperatures of 453K and 673K. This also corresponded to 40 ppb increase in hydrogen concentration in sodium, if all the hydrogen goes into solution.

RMS meter output was digitised at a sampling interval of 0.1s and stored using the data acquisition system. Fig.5 shows the response of transducers ST and SM to hydrogen injection at 453K in the west loop. Experiments showed that the acoustic transducers respond to the presence of hydrogen bubbles in sodium flow and hence has the potential for detecting leaks into low temperature sodium, when hydrogen tends to remain in gas form. Probability density function (PDF) plots for the RMS value of the signal obtained for hydrogen injection at 453K sodium temperature are shown in Fig.6. The plots, which also indicate the detection capability, are useful for evaluating the quality of detection by statistical methods.

For hydrogen injection at 673K, SM showed an increase in signal while ST did not respond. Due to some unknown reason, background signal before injection was very high at ST during this experiment. Response at this temperature will be confirmed by repeating the experiments.

3.4 Future programme at FBTR:

Water/steam circuit of the FBTR steam generator will be commissioned shortly and the reactor power level will be raised to 10.5 MW (thermal). During this phase of FBTR operation, detailed background noise measurements will be carried out at different power levels alongwith gas injection experiments. Measurements will be made with Type-1 and Type-2 accelerometers and acoustic emission sensors to cover a wide frequency range for background noise measurements.

4.0 SIMULATION EXPERIMENTS

Simulation experiments were carried out in the set up shown in Fig.2. Central tube of the seven tube bundle simulates a defective tube with a microhole drilled in it and it is connected to the high pressure gas injection circuit. Wave guides of 20 mm diameter and 1 m long are installed at a location very close to the leak zone and at a distance 7.5 m away from the leak zone. This corresponds to the maximum distance between any leak spot and an adjacent wave guide at FBTR.

Uptill now simulation experiments have been carried out with two defect sizes as indicated below, at test pressures upto 75 kg/sq.cm with argon gas.

Sample tube-1 : circular hole 0.52 mm diameter
Sample tube-2 : hole diameter - 0.36/0.50 on outer surface
0.19/0.20 on inner surface

Holes were drilled by electric discharge machining using tungsten wire electrode. These defect sizes would correspond to a steam leak rate of 1.8 g/s and about 0.28 g/s under nominal operating conditions at FBTR (130 kg/sq.cm and 753K).

Results obtained from these experiments are discussed briefly in the following sections:

4.1 Leak signal characteristics:

RMS value of the signal for an injection pressure of 75 kg/sq.cm measured near the leak and 7.5 m away from the leak, for both the sample tubes are given in Table-1. For comparison, RMS value of sodium flow noise measured at FBTR is also included.

Table - I

Comparison of RMS value of simulation leak signal and sodium flow noise at FBTR

Simulation experiment-argon gas			FBTR		
Sample tube	Near leak	7.5m	West module flow(Cum/h)	ST	SM
1	7680	1630	80 (10.5MWt)	410	320
2	6240	1620			

Note: a) RMS values are given in arbitrary units and are normalised for comparison
b) Flow noise was generally less on the east module

Simulation experiments were carried out at a pressure lower than the steam pressure at FBTR. Moreover, for a given defect size, argon injection is reported to give lower signal level compared to steam injection at the same pressure [2]. Hence it is tentatively concluded from the results given in Table-I that at part load operation of 10.5MWt, even if the total background noise due to water/steam flow increases by a factor of 3 to 4 [3], leak signal would be discernible by monitoring a simple feature like RMS value. However this conclusion has to be confirmed by actual background noise measurements at FBTR during power operation.

Power spectrum plots of leak noise are shown in Fig.7. The leak signal specturm extends to nearly 40 kHz and is broader than the sodium flow noise specturm. Better signal to noise ratio can be achieved by filtering out low frequency part of the signal.

RMS value of the leak signal increased with pressure with an exponent of around 0.3 for sample tube-1. For sample tube-2, there was an initial decrease upto 50 kg/sq.cm and then the RMS value increased with pressure. In the next campaign, simulation experiments will be carried out upto the rated pressure in steam generator (130 kg/sq.cm) and larger defects will also be tested. Firm conclusions regarding leak signal characteristics can be drawn after these measurements.

4.2 Injection into empty shell:

Steam generator tubes are back filled with nitrogen at approximately 5kg/sq.cm and sodium is drained from the module after a leak signal is detected by hydrogen detectors at FBTR. If the leak passage remains open and if a measurable acoustic signal results from gas leak into the empty shell, it will be possible to confirm the leak and also identify the section where leak has occurred.

Simulation experiments with empty shell showed that for sample tube-1, an injection pressure of around 5 kg/sq.cm and for sample tube-2, an injection pressure of above 12 kg/sq.cm resulted in detectable signal levels.

4.3 Cross correlation experiments:

One of the advantages of acoustic leak detection system is its ability to localise the leak by cross correlation technique. Cross correlation experiments were carried out in the simulation set up at an injection pressure of 12 kg/sq.cm.

Cross correlation measurements were carried out using a dual channel signal analyser. Initial experiments with injection into water filled shell did not yield a peak in the cross correlation function around the expected transit time. Experiments were done for different band widths of the signals and analysis also covered adequate delays. Spacing between the transducers was varied from 1.5 m to 7.5 m. This negative result was considered to be due to the standing waves present in the model and due to the effect of gas bubbles in the sound transmission path. Gas bubbles also reduce the velocity of sound.

Experiments were repeated for injection into empty shell. Results were not satisfactory. To confirm that batch processing mode of the analyser did not contribute to errors in cross correlation function, computation of cross correlation function was made using software approach on data digitised for a long duration of time. Result is shown in Fig.8 and again no distinct peak was obtained.

Failure to localise the leak in the simulation set up is at present attributed to the following reasons.

a) Standing waves
b) Multiple transmission paths
c) Poor correlation between the signals
d) Effect of gas bubbles in sound transmission path

Additional experiments are being planned to understand these phenomena and in turn try to develop a suitable localisation technique.

5.0 ACOUSTIC LEAK DETECTION SYSTEM FOR PFBR STEAM GENERATOR

Each of the four secondary loops of Prototype Fast Breeder Reactor consists of 3 steam generator modules. Each module consists of evaporator, superheater and reheater and these are basically once through shell and straight tube heat exchangers. Design details are given in Ref.4. Nickel membrane diffusion type in-sodium hydrogen detectors with mass spectrometer are proposed at the outlet of each evaporator and in the common sodium return line to secondary pump. This leak detection system is capable of protecting the steam generator for leaks between 0.09 g/s and 0.27 g/s at superheater top, before adjacent tube wastage occurs.

An acoustic leak detection system is envisaged for PFBR steam generators, playing a supplementary role to the hydrogen detectors. There are stagnant sodium zones at inlet and outlet of the steam generator near thermal baffles and in-sodium hydrogen detectors will be ineffective for leaks in these zones. One of the main objectives of the acoustic leak detection system at PFBR is to protect the steam generator modules against leaks in the stagnant zones. Another important area envisaged for acoustic leak detection is to provide protection against rapidly escalating leaks.

Twenty mm diameter wave guides are proposed to be installed on the top and bottom tube sheets, near inlet and outlet stagnant sodium zones and on the shell at nearly 4 m span. High frequency (100-1000 kHz) acoustic emission sensors are being considered for the tube sheet wave guides and at other wave guide locations accelerometers or acoustic emission sensors will be installed depending on the results from experimental studies. Signals from these transducers will be processed at local control stations in steam generator buildings and output data will be transmitted to the control room. The role of acoustic leak detection system at PFBR will depend on the results from the development programme.

There is a proposal to set up a sodium-water reaction test facility in which microleak behaviour, impingement wastage and leak detection methods can be studied in suitable test sections simulating PFBR steam generator conditions. Acoustic leak detection experiments are also planned in this facility.

6.0 CONCLUSIONS

This paper has given an insight into the programme at IGCAR to develop an acoustic leak detection system for use in LMFBR steam generators. After completing the first phase of the experimental programme related to FBTR, work for developing a suitable system for PFBR will be undertaken.

7.0 ACKNOWLEDGEMENT

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carrying out measurements at FBTR is gratefully acknowledged.

8.0 REFERENCES

1. Personal communication from FBTR Commissioning group.

2. Recent experiments on acoustic leak detection: J.Voss and N.Arnaoutis; Proceedings of IWGFR Meeting on "Theoretical and experimental work on LMFBR steam generator integrity and reliability with a particular reference to leak development and detection", Netherlands, Nov. 1983.

3. Water leak detection in steam generator of Super Phenix: M.Brunet et al; Specialists' Meeting on Reactor Noise, SMORN V, Munich, FRG, Oct. 1987.

4. Design of PFBR steam Generators: S.C. Chetal et al; Specialists' Meeting on 'Steam Generator Failure and Failure Propogation Experience' , 28-30 Sept. 1990, Aix-en-Provence, France.

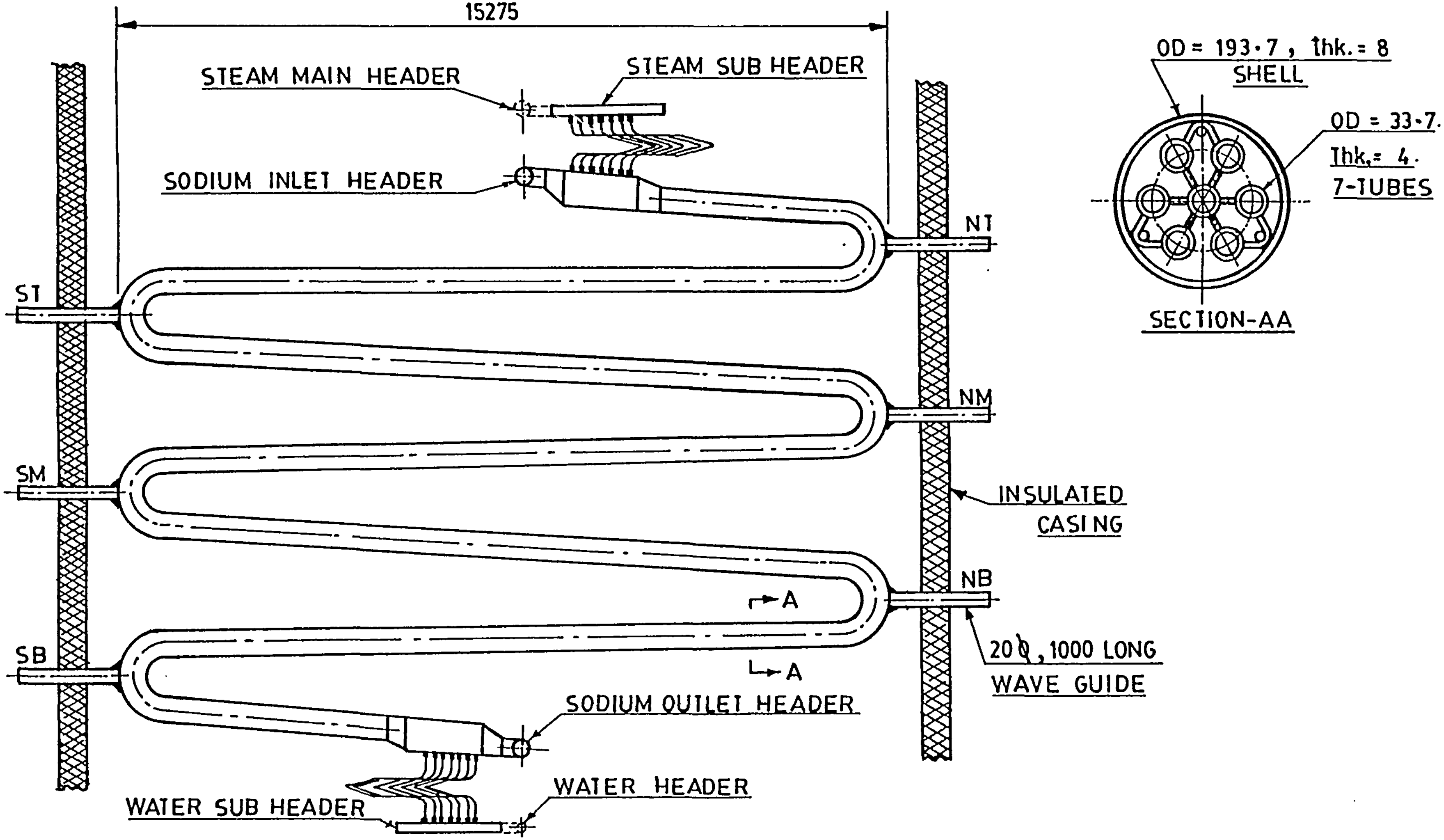
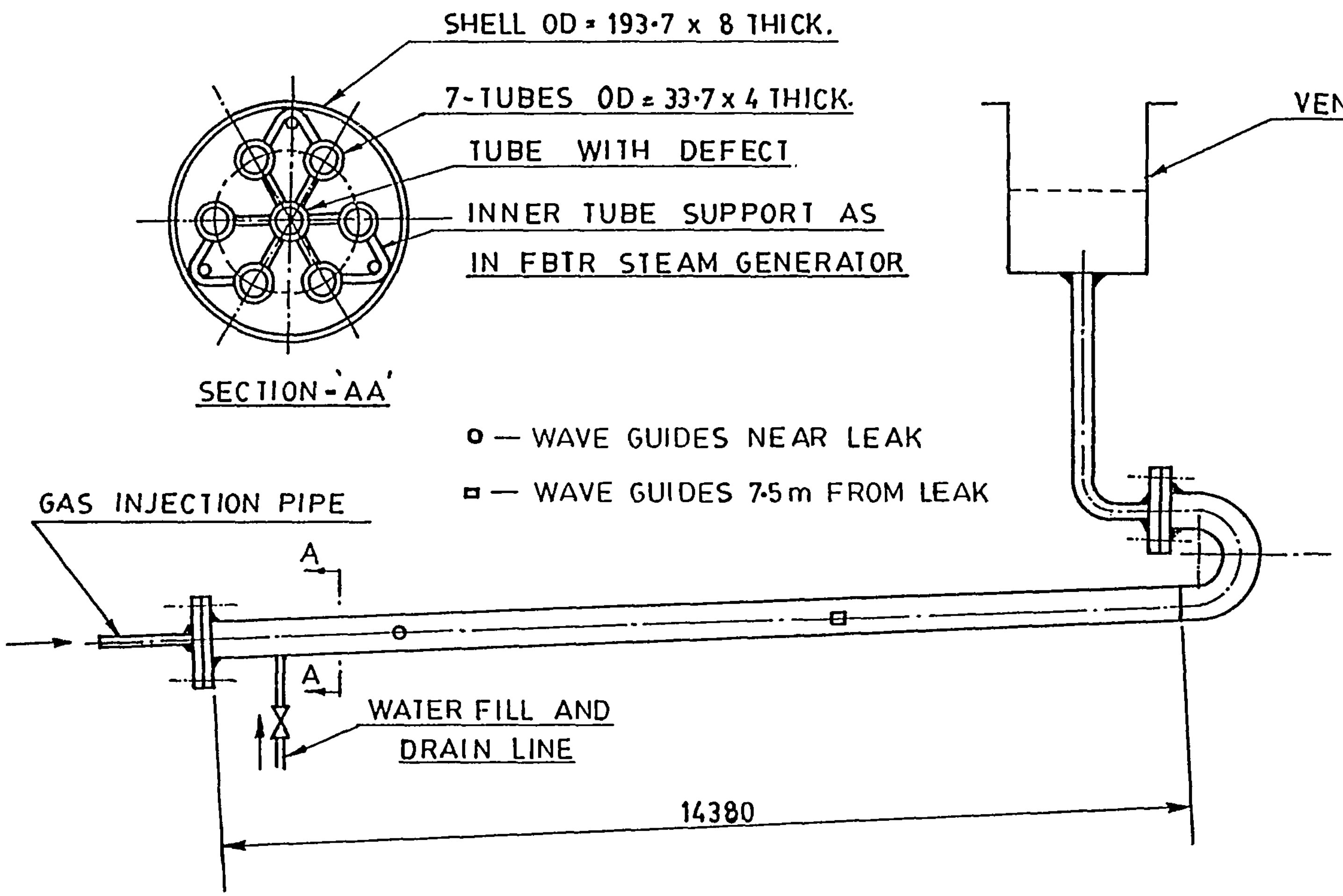


Fig- 1. FBTR STEAM GENERATOR MODULE WAVE GUIDE LOCATION



NOTE:- 1. 6-TUBES OPEN AT BOTH ENDS.

2. CENTRE TUBE DUMMIED AND TAKEN OUT THROUGH FLANGE FOR GAS INJECTION.

Fig-2. SIMULATION EXPERIMENT SETUP

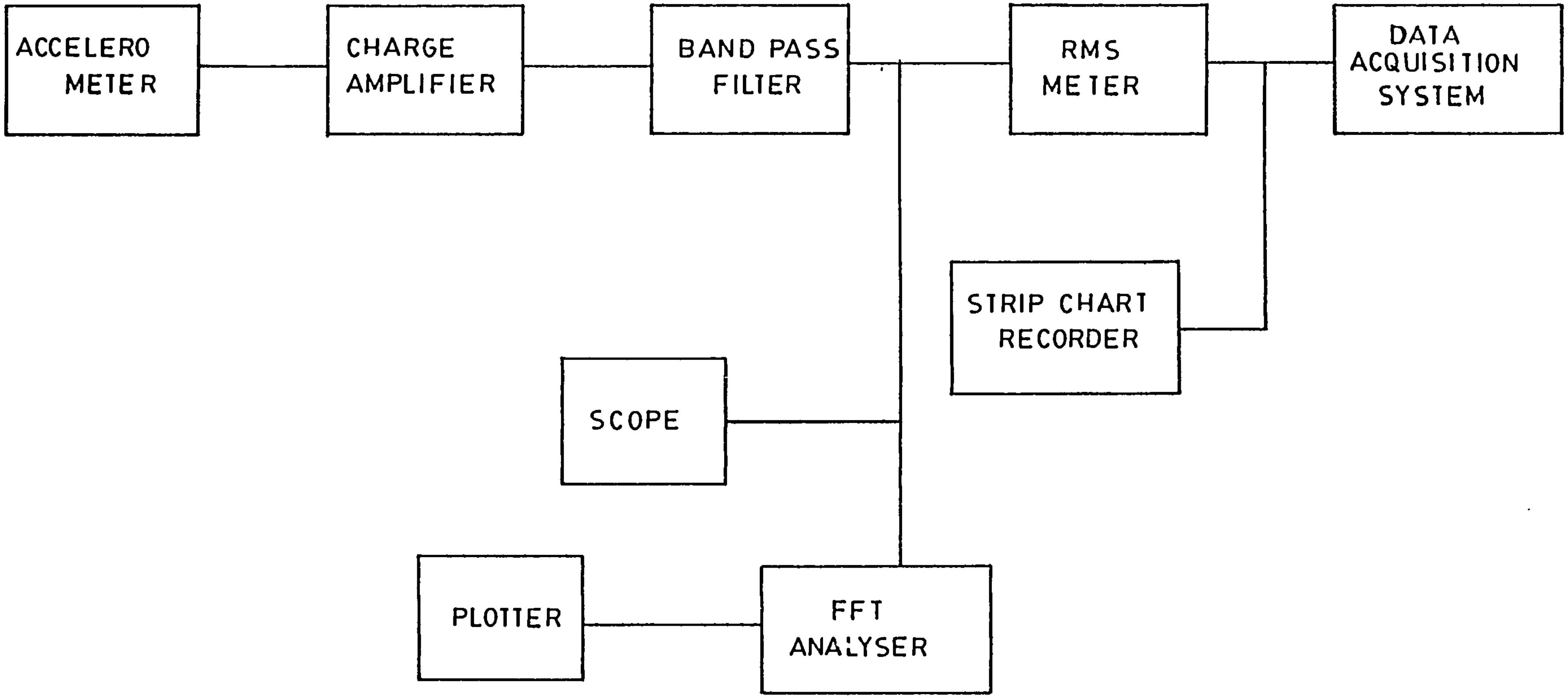
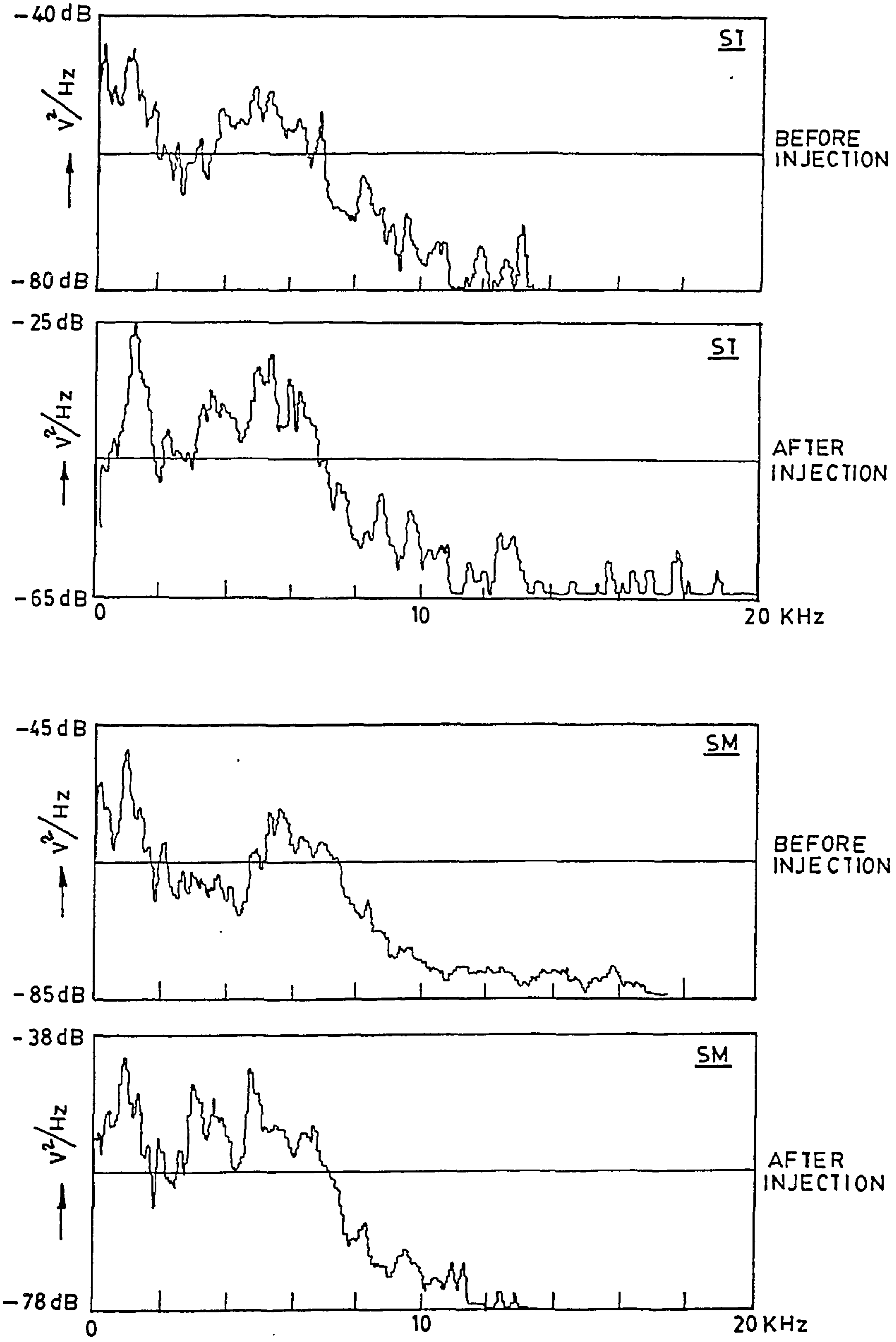
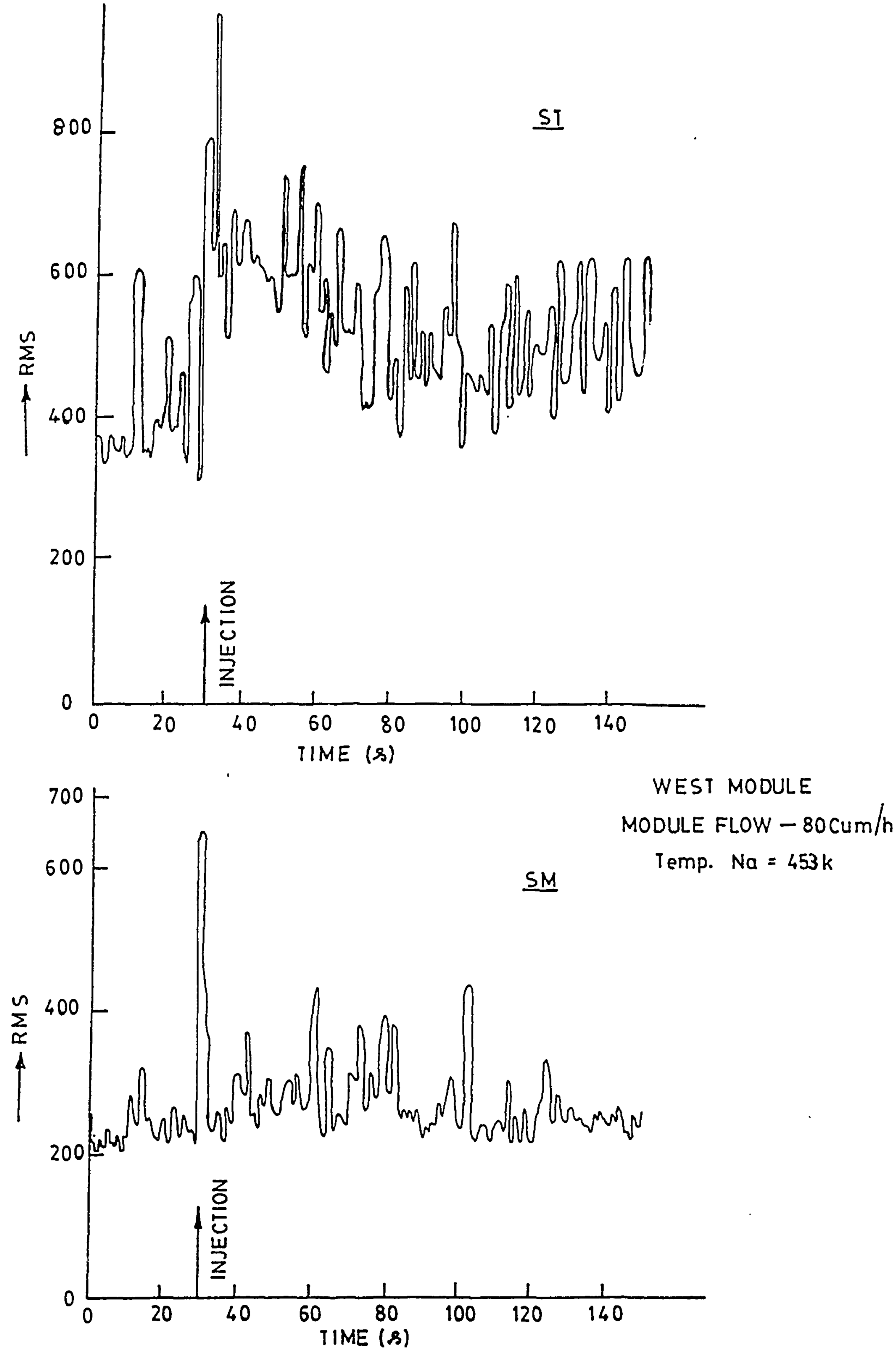


Fig - 3. INSTRUMENT SCHEMATIC



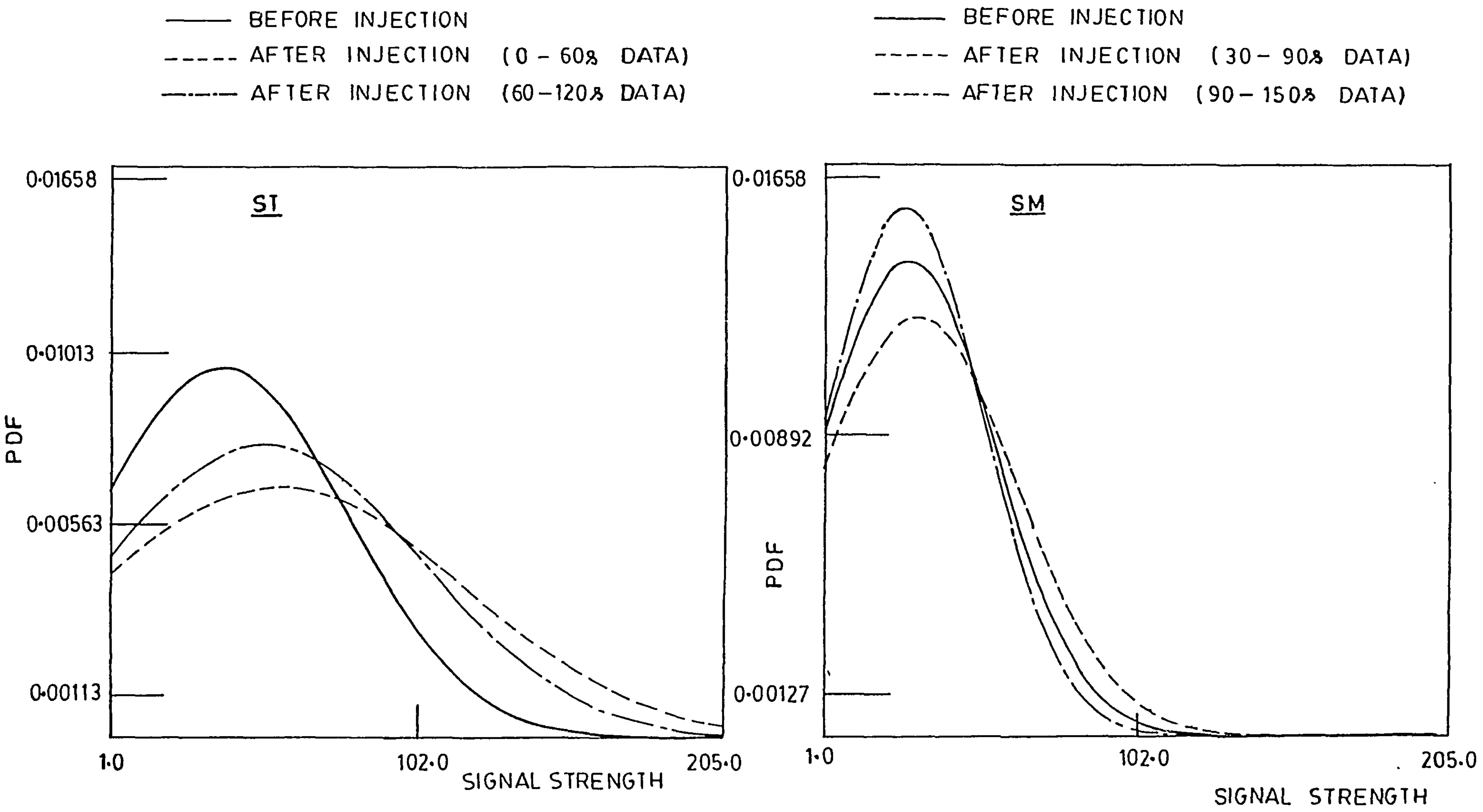
MODULE FLOW — 80 Cu.m/h ; WEST MODULE .

Fig-4. PSD OF FLOW NOISE BEFORE AND AFTER ARGON INJECTION



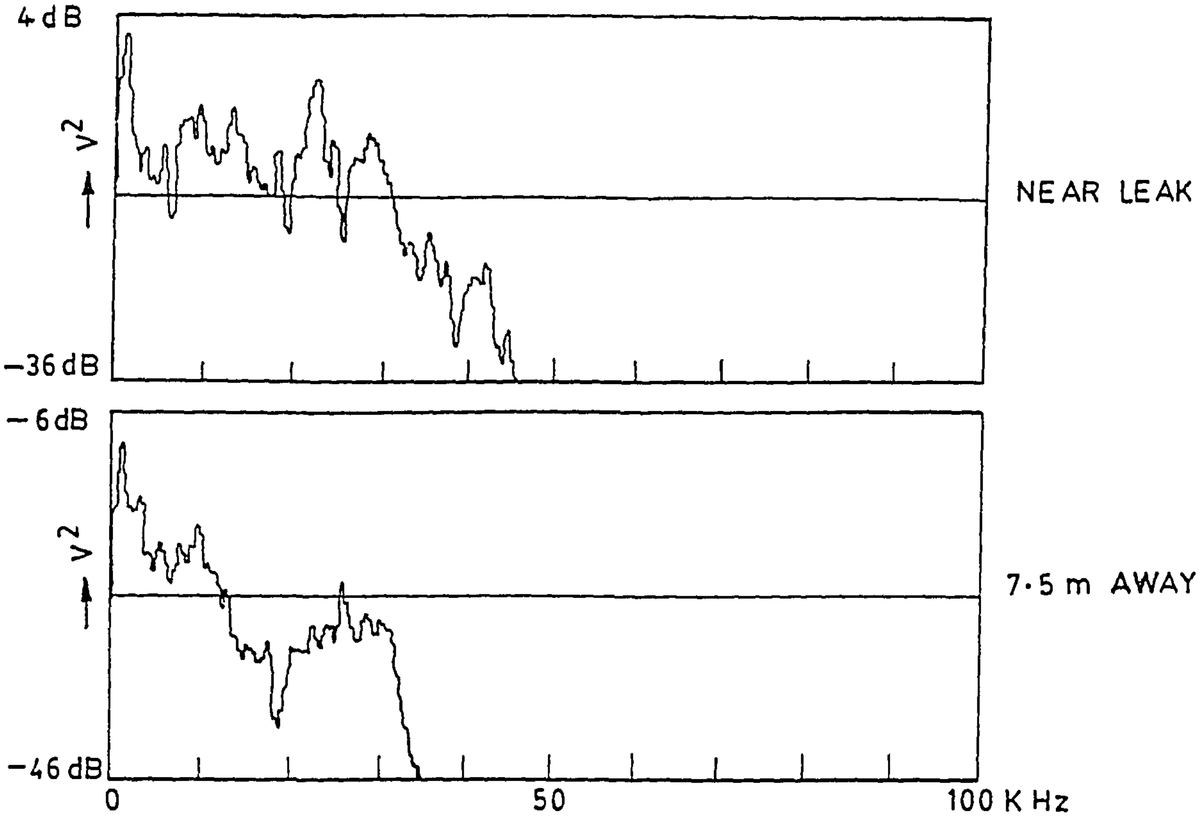
WEST MODULE
MODULE FLOW — 80 Cum/h
Temp. Na = 453 k

Fig-5. RESPONSE TO HYDROGEN INJECTION

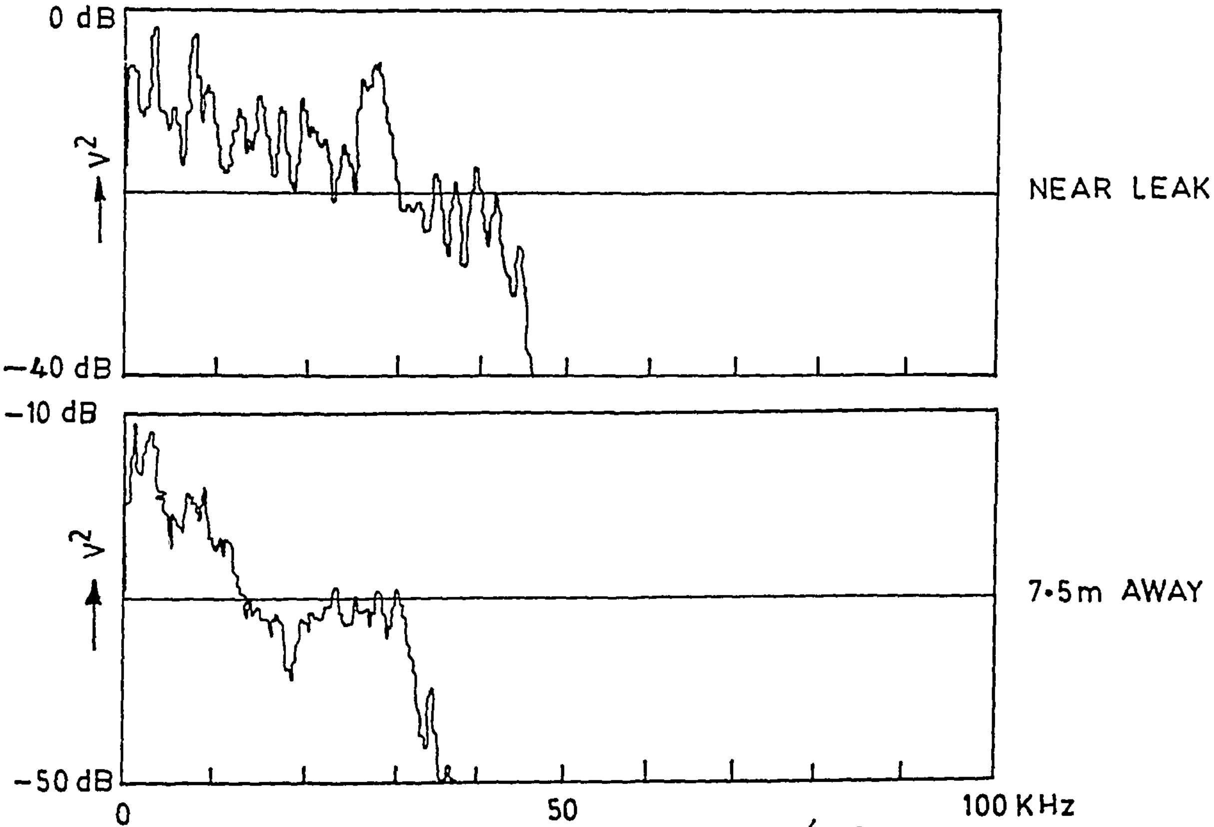


MODULE FLOW – 80 Cum/h ; WEST MODULE

Fig-6. PDF PLOTS OF RMS VALUE FOR HYDROGEN INJECTION



SAMPLE TUBE-1 : ARGON – 75 Kg/Cm^2



SAMPLE TUBE – 2 : ARGON – 75 Kg/Cm^2

Fig-7. PSD PLOTS FOR LEAK SIGNAL

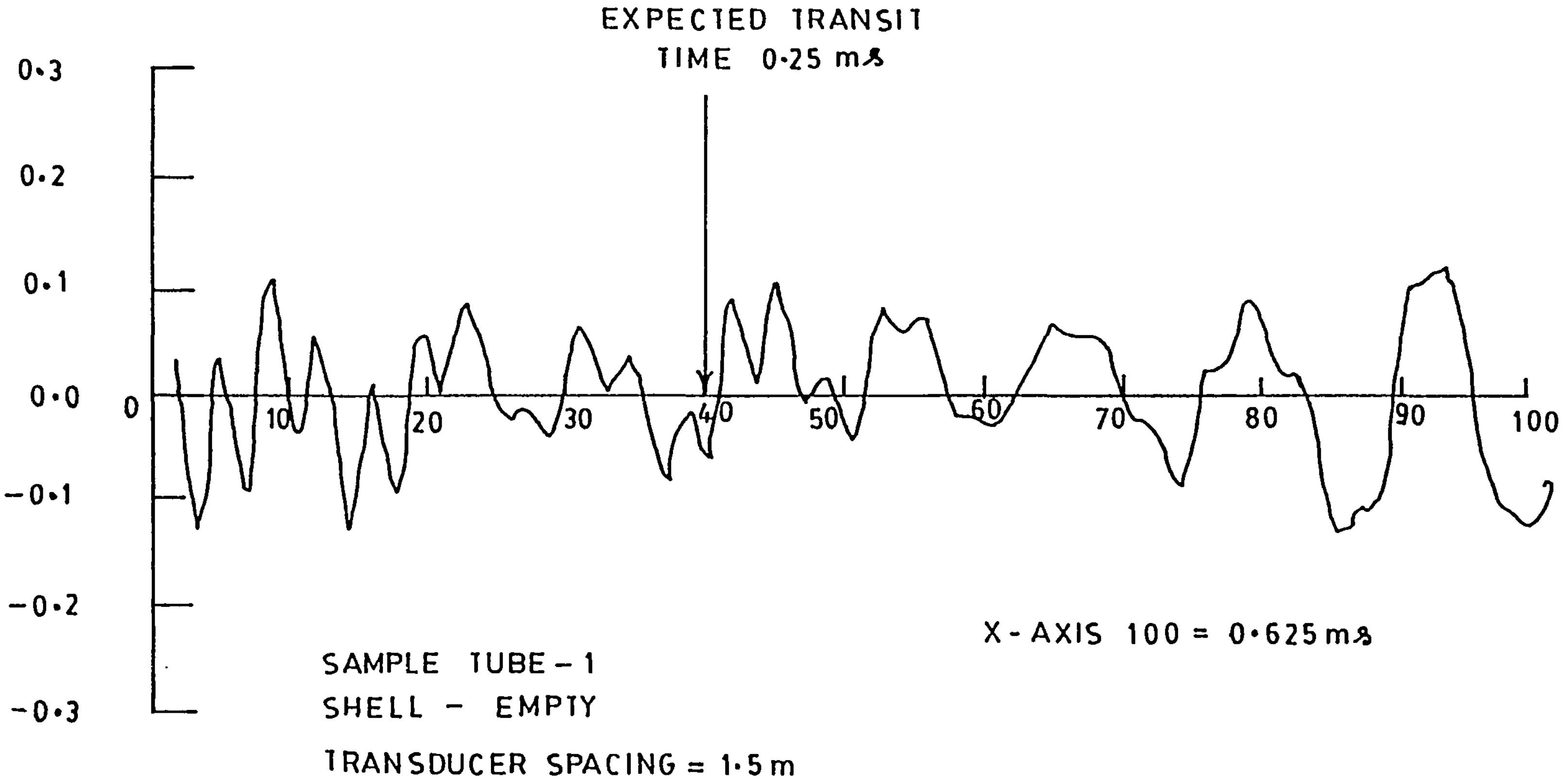


Fig-8. CROSS CORRELATION FUNCTION