EXPERIMENTAL STUDIES ON ACOUSTIC DETECTION OF SODIUM-WATER STEAM GENERATOR LEAKS IN THE USSR.

The Specialists'. Meeting to be held by IWGFR IAEA, 1-3 October 1990, Aix-en Provence, France.

SM2 - Steam Generator: acoustic ultrasonic detection of in-sodium water leaks.

Petrenko A.A., Poplavsky V.M.

This paper has been prepared on the base of work carried out by authors' teams from the Institute of Physics and Power Engineering (Obninsk):Kozlov F.A., Zakharov S.O., Uralets A.Yu., Yugay V.s., et al and from the Nuclear Reactors Research Institute (Dimitrovgrad): Golushko V.V., Dunayev V.S., Kuznetsov A.M., Sokolov V.M. et al with the participation of the BN-600 team and BOR-60 operating personnel.

Institute of Physics and Power Engineering
Obninsk, 1990.

INTRODUCTION

The detection of acoustic signals characterizing a steam generator leak takes place under conditions of various type noise signal of a technological character (pumps, valves, hydraulics, etc.).

From this it follows that besides scientific and engineering problems connected with the identification of the steam generator leak phenomenon it is necessary to characterize and take into accout various kcinds of noise, i.e. the competitive noise.

It should be noted that in case of an in-sodium water leak in a steam generator a local temperature increase and sodium boiling take place resulting in generation of a random signal with a wide frequency spectrum.

A considerable number of experiments on the detection of steam generator leaks under modelling and commercial conditions allows to state that the leak noise characterized by a stationary random process with ergodic properties. This statement determines the methodological bases and trends of mathematical treatment on the leak event detection.

Due to the competitive noise which presents the main problem at determining the "useful", as well as than the character of this noise varies from plant to plant it follows that the identification is possible to a considerable degree only under real plant conditions.

The dynamic range of leak variation is from some thousandths to hundreds of grams of water per second. It is a difficult problem to provide such a range of measurements by one device. In this connection the development of methods and means capable to ensure the detection of water leaks within a wide range becomes a vital problem.

1. EXPERIMENTS AT FACILITIES AND THE BN-600. GENERAL CHARACTERIZATION OF THE SYSTEM.

The acoustic leak indicators have been developed in two versions. The first version of the system is based upon using the immersible acoustic hydrophones and the parallel frequency analysis of their signals. The second one is based upon using the waveguide sensors with the microprocessor system of noise signals processing. In this case, an angle of slope of the polar autocorrelation function and its comparison with the previously chosen setting is used as an informative parameter. This version has been realized at the BOR-60 facility.

For the realization of the first version a multichannel frequency analyzer conjugated with a microprocessing leak analyzer has been developed and made. The frequency analysis is performed by means of an analog device. Due to this, the statistical processing of signals is realized on a comparatively small computer. As an initial information, the amplitude and frequency characteristics of original signals are used.

The block diagram of the system is presented in Fig.1.

It consists of 15 independent analog converters of signals (1-15) coming from wide-band preamplifiers (WBPA) and acoustic detectors (AS).

The converters are made according to the same diagram that provides the parallel isolation from the input signal of components in four frequency ranges and the generation of output signals proportional to the current average value of an amplitude of each of the components. The output signals of converters are multiplexed by means of the 799/2 commutator after that they enter the microprocessing analyzer to be used in a specialized leak detection algorithm. The information is put to the display and numerical printer.

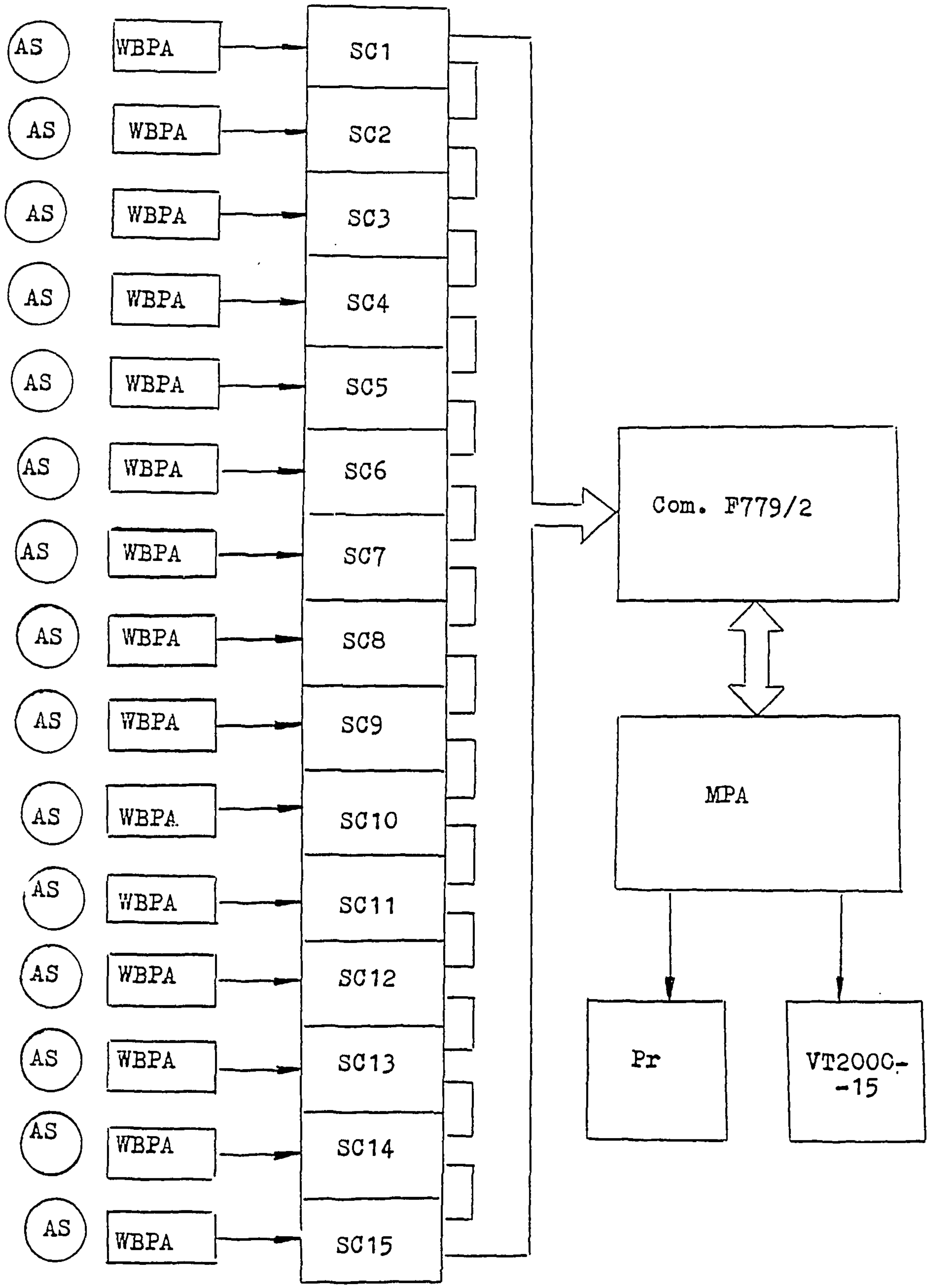

Fig.1. Block diagram system SOTA 15.

The signal from the corresponding WBPA is fed to the wide-band scale amplifier with a transmission ratio discretely changing from 2 to 10. The transmission band of the scale amplifier is 1-200 kHz. After amplifying and scaling the signal is fed to 4 in-parallel component-isolating circuits which differ in the choice of band filter cut-off frequencies.

The values of band filter cut-off frequencies are as follows:

F1	f^{l}_{cv} = 1 kHz	f^{h}_{cv} = 8 kHz
F2	f^{l}_{cv} = 8 kHz	f^{h}_{cv} = 20 kHz
F3	f^{l}_{cv} = 20 kHz	f^{h}_{cv} = 40 kHz
F4	f^{l}_{cv} = 40 kHz	f^{h}_{cv} = 200 kHz

The band filters are made of the active elements according to the scheme of the third-order Butterverth filters that ensures the characteristics outside a transmission band of 18 dB/(oct).

The signal detection is performed by linear detectors with the following averaging by the integrating circuit. The rate of the system reference to each of the output signals may be up to 200 measurements per second.

The block diagram of the signal converter is presented in Fig.2. The technical characteristics of the SOTA-15 system are as follows:

- The number of simultaneously connectsd detectors (preamplifiers) - 15
- The number of frequency bands - 4
- The input resistance of signal converters, R ohm - 10
- The range of signal converters' transmission factor variation - 2-100
- Averaging time, sec - 0.5

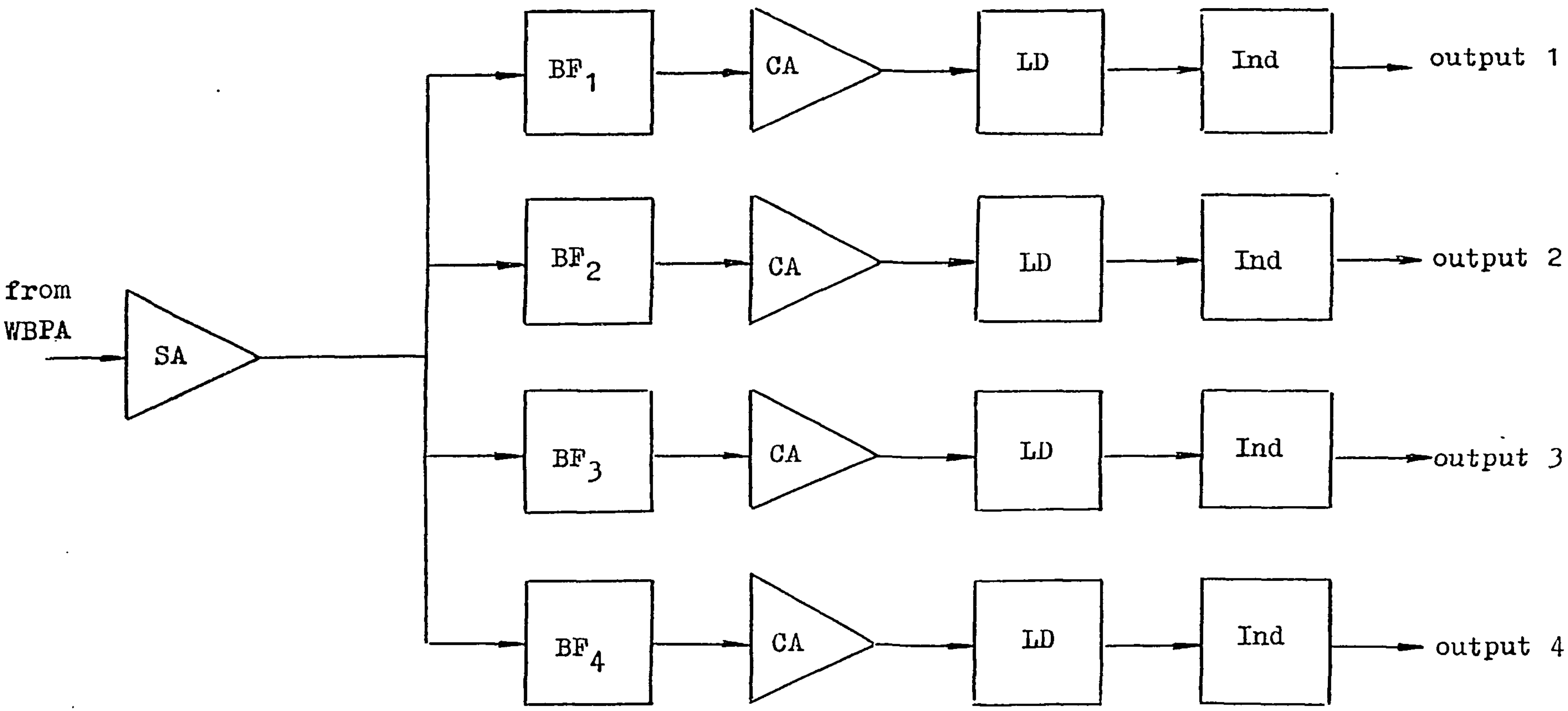

Fig.2. Block diagram of the signal convertor.

1.1. Results of "SOTA-15" Tests at the Experimental Section and at the BN-600 6AI Section Steam Generator.

a) Tests at the Experimental Section.

Prior to mounting of the acoustic system at the BN-600 unit it was tested under sodium facility conditions at the experimental section with leak simulation by means of forced measured injection of argon and hydrogen through a special feeder into circulating sodium. In the measurements, the immersion hing-temperature acoustic receivers were used.

The signals trom preamplifiers were fed through cable communication lines into the "SOTA-15" system in which their filtration, detection and averaging were performed.

The test result are presentsd as graphs of the output signals variation in 4 frequency bands and include measurements before, during and after injection.

The injection feeding time was 30 sec.

The results and conditions of experiments conduction are presented in Figs.3,4,5.

The experiments at the facility have shown:

- At the injection of argon and hydrogen a practically instantaneous increase of the signal level in all the four frequency bands is observed. The maximum signal level is observed in a frequency band of 1-8 kHz. The signal level decreases successively with the frequency increase. In this case the signal-to-noise ratio in all 4 frequency bands is 50.

- Under conditions of an experimental section with the tube bundle, at hydrogen injection through the lateral feeder with a flow rate of 0.3 ml/sec. the signals of the acoustic receivers mounted at a distance of 150 mm and 1650 mm have a comparable value. A signal decrease is observed at a distance increase in a band of 8-20 kHz. At the same time, a signal increase is observed in a band of 40-200 kHz.

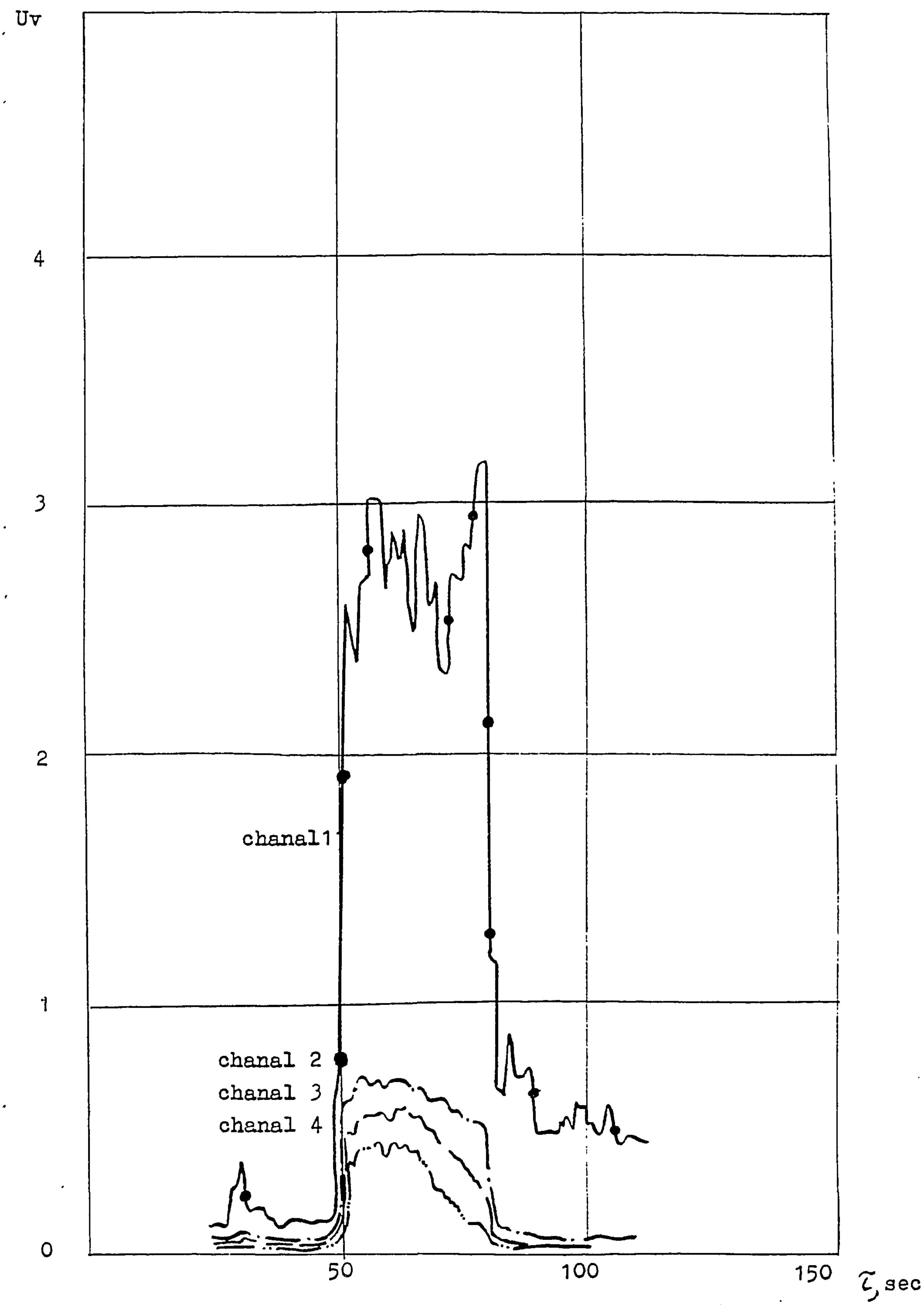

Fig.3. Signal dynamic SOTA 15 (injection Ar)

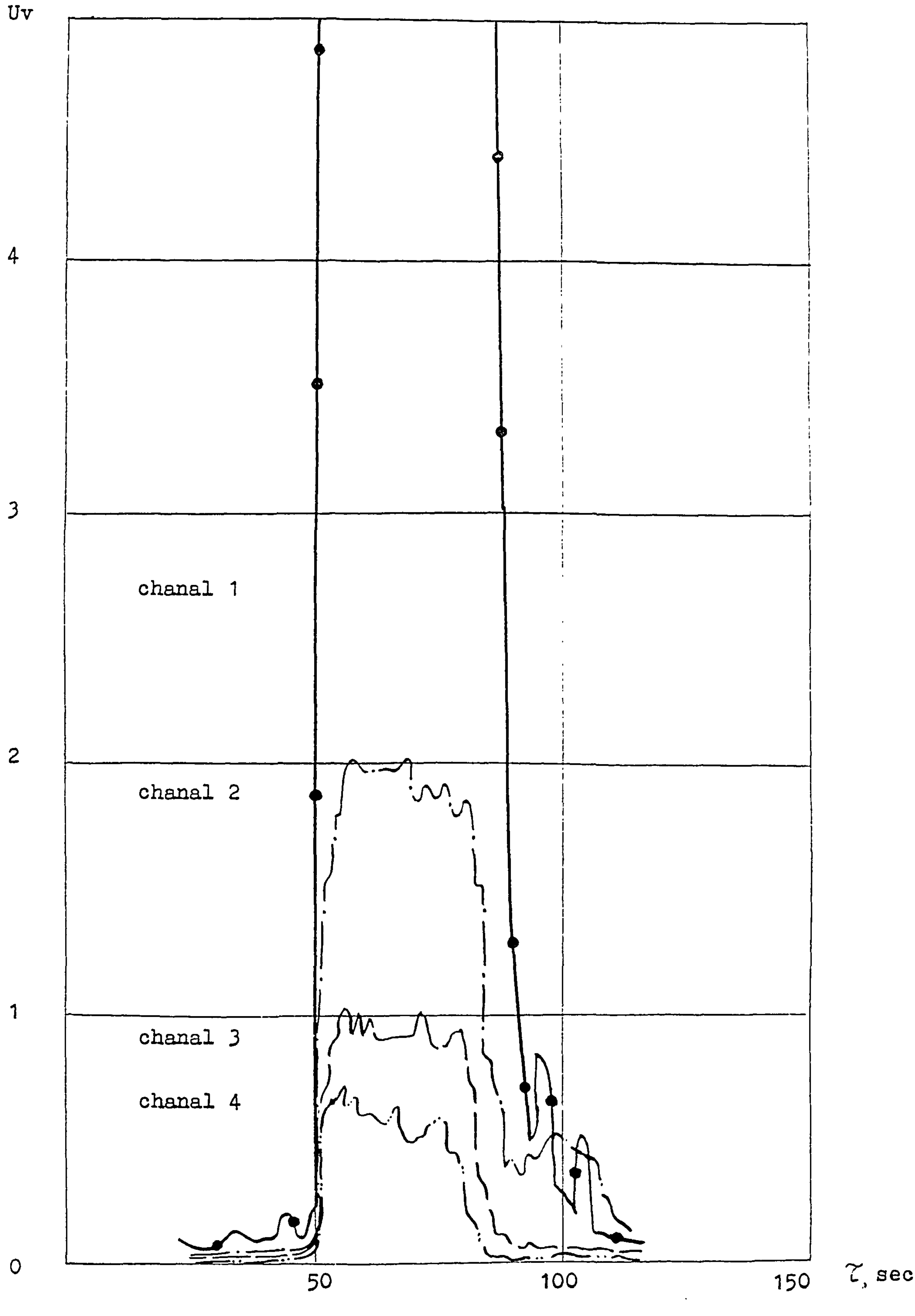

Fig.4. Signal dynamic SOTA 15 (injection H_2).

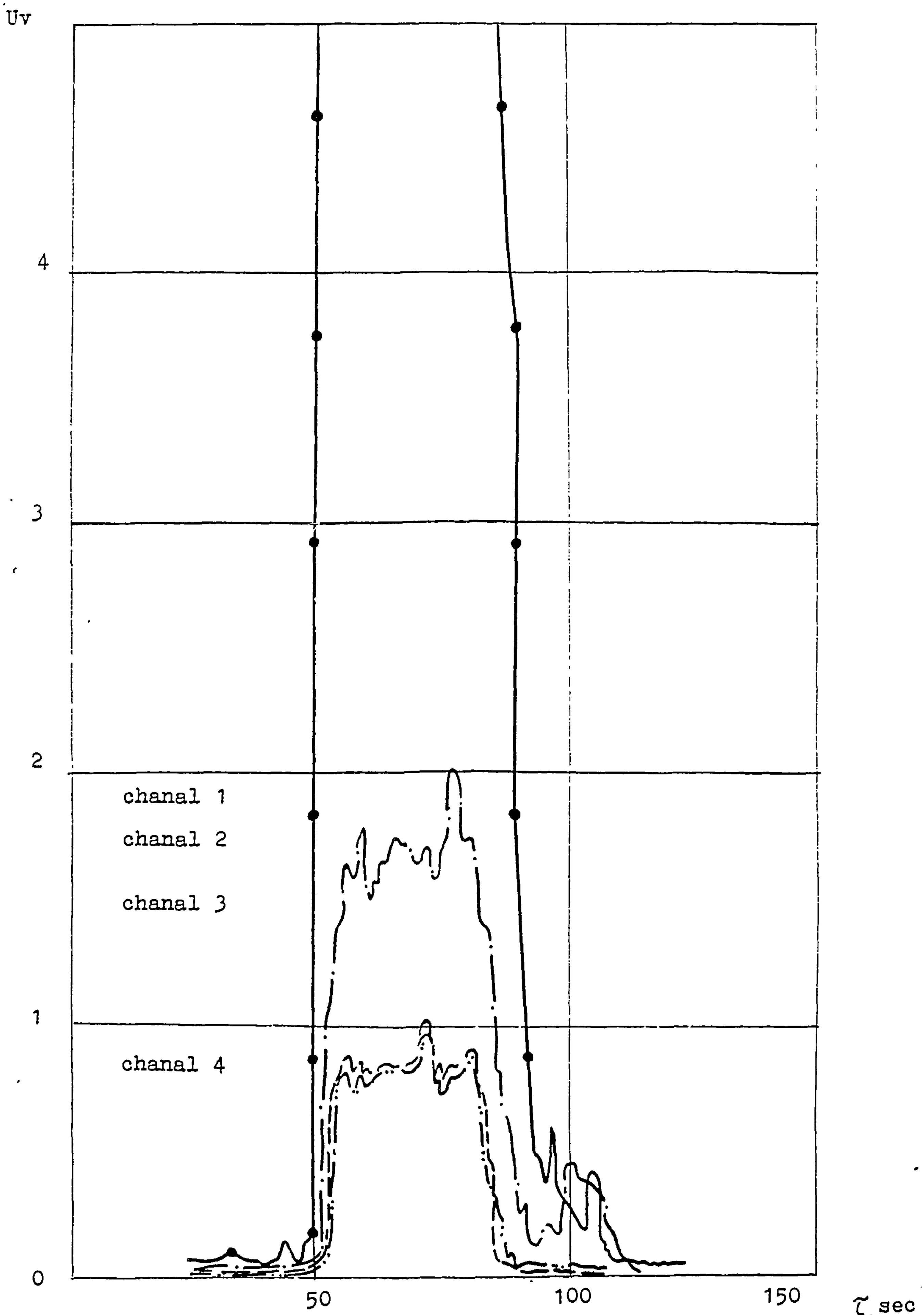

Fig.5. Signal dynamic SOTA 15 (injection H_2).

- After closing the feeder (hydrogen injection stopping) for a durable time (30-40 sec) a signal decrease to a level of the background one is observed in a frequency band of 1-8kHz and that of 8-20 kHz. In the supersonic frequency range the time of signal level decreasing to the background value is 5-8 sec.

- At comparable argon (0.32 ml/sec) and hydrogen (0.3 ml/sec) injection rates, the signal level in all 4 frequency bands at hydrogen injection exceeds considerably the corresponding levels of signals at argon injection.

- The tests have showm that in all 4 frequency bands there is reliable monitoring of leak noise, the effect-to-background ratio being about the same for all frequency ranges.

b) Tests at the BN-600 SGU-200M Steam Generator.

The high-temperature acoustic detectors were mounted at the following places (see Fig.6):

1. The upper chamber of the MSH module of the 6AI section.
2. The bottom cell of the EY module of the 6AI section.
3. The bottom cell of the ISH module of the 6AI section.

The injection device is mounted in the bottom cell of the MSH module of the 6AI section in such a way that the measured gas injection is carried out into the intertube space of the ISH module.

In the course of experiments the acoustic noise was measured for the three sets of argon and hydrogen injections.

The 1 set (17 injections) - with the drained 3 circuit;

The 2 set (9 injections) - with the filled 3 circuit;

The 3 set (8 injections) - at a power of 87%.

The measurements were carried out according to the following scheme. The signal from each of the 3

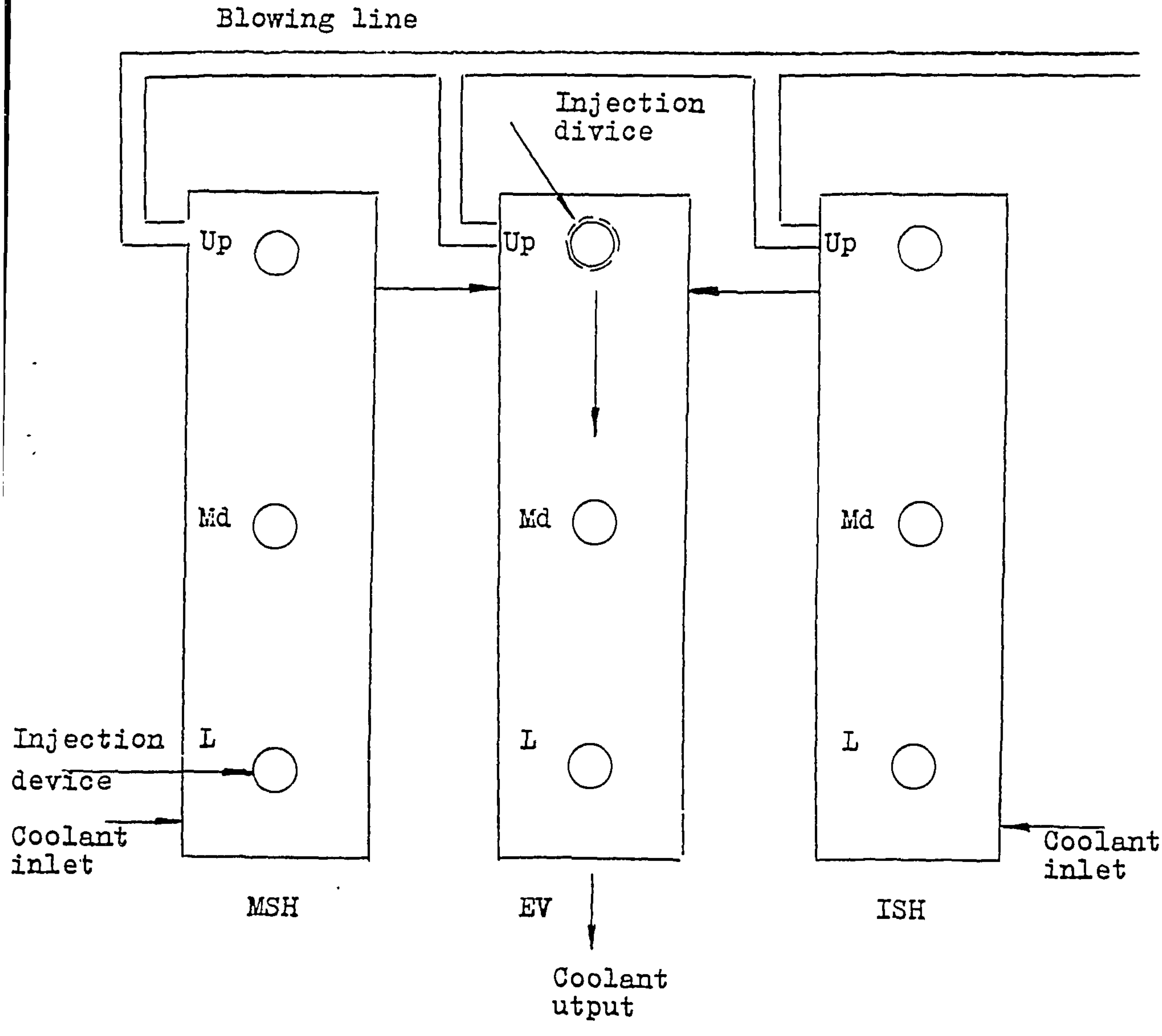

Fig.6. Diagram of sensor arrangement at SGU.

hing-temperature acoustic detectors amplified by the preamplifier in a frequency band of 1-200 kHz was fed at the 'SOTA-15" input. The detected and averaged signal was then monitored by the loop oscillograph H-117/2.

Hudrogen injection into the bottom chamber of MSH was carried out at an initial pressure of 37-40 kg(f)/cm^2 with flow rates of 14-270 ncm /sec.

The results obtained are characterized by the following features:

- At injection with a flow rate from 14 to 40 H cm^3/sec the signal growth is unstable and represents a random pulsed process. The signal value at some time intervals (8-10 sec) reaches 10v in a frequency band of 1-8 kHz for an injection of 46 n cm^3/sec.

- At hydrogen injections with a flowrate of 100 n cm^3/sec and more an instantaneous increase of the signal is observed and in 1.5-2 sec the signal value reaches an ultimate monitored value of 10v both for the receiver in the MSH and for the receiver in the EV. In this case for the detector in the EV an increase of the peak magnitude and recurrence frequency is observed.

- As at argon injections, a signal delay of the acoustic receiver in the EV is observed.

- At hydrogen injections with a flow rate of 100 n cm^3/sec and more a signal increase in a frequency band of 8-10 kHz is observed.

1.2. AN EXPERIMENT WITH THE 3 CIRCUIT FILLED WITH WATER. ARGON AND HYDROGEN INJECTION.

Amplification of the signal in a frequency band of 1-8 kHz was decreased 10 times and amplification in a frequency band Of 8-20 kHz was increased 5 times. A hydrogen injection was 270 n cm^3/sec (squivalent to 0.4 g/sec of water).

Under these cOnditions a swift growth of signals in both frequency bands is observed. In 1-2 sec the signal value reaches an ultimate monitored signal value of 10v (Fig.7).

Argon injection was carried out at an initial pressure of 40 kg(f)/cm^2 and flow rates from 27 to 178 n cm^3/sec.

Signals from acoustic sensors at argon injections after filtration and detection in "SOTA-15" and recorded on the loop oscillograph tape are characterized by the following features:

-In all cases of argon injections an increase of the detector signal in MSH is observed; in this case both the average value of the signal and its dispersion in a frequency band of 1-8 kHz increase.

- Similar variations of the signal take place also in EV, the signal structure in EV, however, differs from the signal structure in MSH. It represents a sequence of peaks upon the average value of the signal, the value and frequency of whose succession increases with argon flow rate.

- A delay of signal from the sensor in EV after the moment of injection into MSH is observed which is probably caused by the time of bubble transport from the bottom chamber of MSH into the evaporator module.

In Fig.8 results of an experiment at argon injection with a flow rate of 104.2 n cm^3/sec are shown.

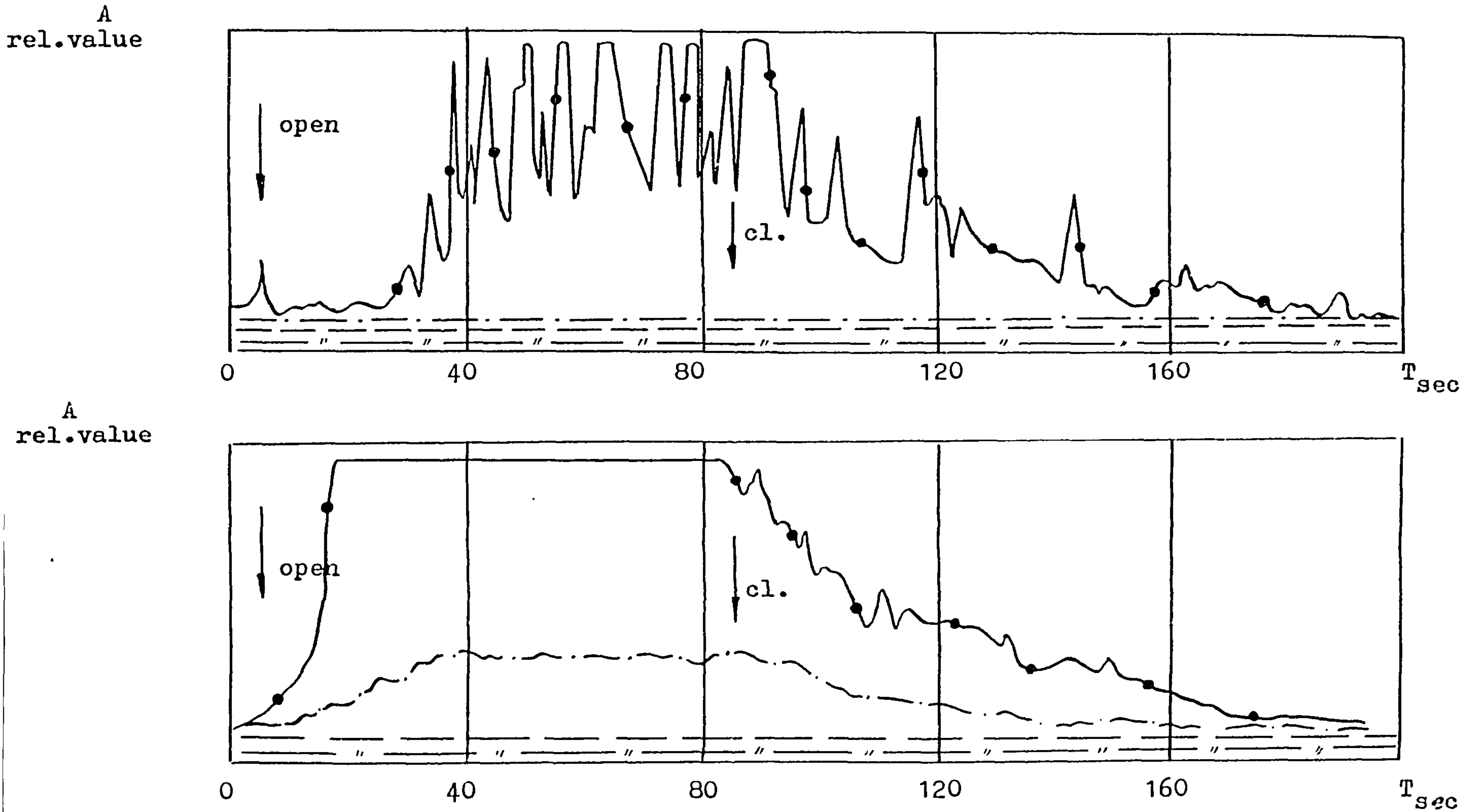

Fig.7. Record of output signals SOTA 15 (Injection H_2 in modul MSH).

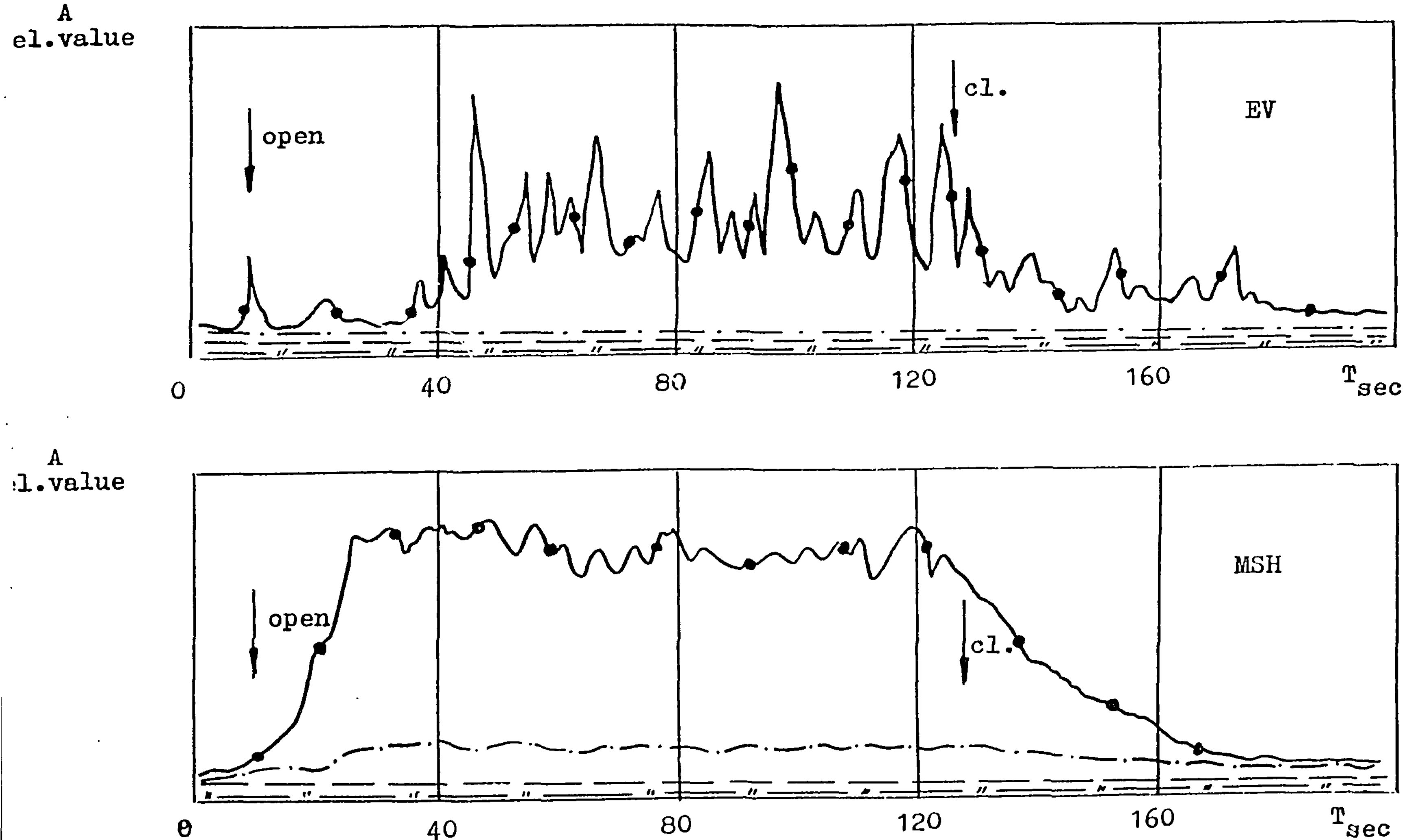

Fig.8.Record of output signals SOTA 15 (Injection Ar in modul MSH).

1.3. AN EXPERIMENT AT 87% POWER RATING.

Injection of hydrogen and argon into the bottom cell of MSH is carried out at an initial pressure of 40 kg/cm^2 with the following flow rates: for argon - of 98 and 75 n cm^3/sec; for hydrogen - of 500; 27.5; 54.5; 87.340 n cm^3/sec.

The background noise of all acoustic sensors measured during this series of injections had a large harmonic disturbance the frequency of which was estimated to be 10 kHz. In this case the signal level reached an ultimate recorded value of 10v. In the presence of this disturbance there could not be visually ascertained any facts of agron and Hydrogen injection at 87% steam generator power rating.

From the above it follows:

- The tests conducted have shown that when modelling small leaks by means of argon and hydrogen injection into the tube bundle it has been possible to to detect a (5-10 times) excess of the signal above the background level in all cases except for regime at 87% power rating.

- If, however, under conditions of the test section at the facility, the leak effect was revealed in all frequency ranges with about the same useful-signal-to-background ratio, then under conditions of the BN-600 steam generator in two hing-frequency intervals (20-40 kHz and 40-200 kHz) it was practically absent.

It can be assumed that such a result might be due to the absorption of hing-frequency supersonic oscillations by argon bubbles distributed in sodium.

Later on, it is necessary to test this hypothesis.

- Another characteristic property of the recorded noise is a delay in an increase of the signal from the detector mounted on the evaporator relative to the beginning of an increase of the signal from the detector mounted on the main superheater. The delay is 10-15 sec and practically coincides with the time of gas bubbles transport from the point of injection to the place of detector siting in the evaporator. This points to the fact that the low-frequency signal from the detector placed on the evaporator is a result of sound generator in a moving mixture of gas and sodium bubbles. The presence of such a mechanism of sound generation causes anxiety that random entrainment of argon in the expansion tank and its further propagation over the sodium circuit can cause spurious increases in the detector signals from which it is difficult to tune away.

- Because of the above difficulties in the realization of acoustic methods and due to incompletion of investigations, in the USSR at the operating fast reactor plants the concentration methods and deveces are used for steam generator leak monitoring. Large useful experience was gained on these devices and they provide steam generator leak monitoring at the BOR-60, BN-350 and BN-600 plants.

2. EXPERIMENTS AT THE BOR-60. WAVEGUIDE DETECTORS AND THE USE OF THE SIGNUM AUTOCORRELATION FUNCTION (ACF) AS AN INVORMATIVE PARAMETER.

In Fig.9 a schematic diagram of arrangement of the acoustic detectors and injection device at a steam generator is shown:

1 - the first sensor;

2 - the second sensor;

D- injection device.

A device for water steam and argon injection is mounted on the over flow sodium pipeline. The waveguide sensors 1, 2 are mounted on the superheater at injection device level. They are welded to the steam generator vessel.

Through the system of measured gas supply through the nozzle of 0.1 mm in diameter several argon injections with various flow rates were carried out. The time of each injection was 3 min. The result of experiments on leak modelling by means of argon injection were recorded on the magnetograph. An analysis of argon leak noise results is presented below.

2.1. ARGON LEAK NOISE ANALYSIS.

At processing the argon leak noise records with the use of the acoustic noise analyzer the (leak signal+background/background) ratio as a function of frequency for the $k(\tau)$ and $\tilde{H}(\tau)$ parameters was investigated where

$$k(\tau) = H(\tau_1) - H(\tau_2) / (\tau_2 - \tau_1)$$

and $\check{H}(\tau)$ - the normalized signum autocorrelation

$$\tilde{H}(\tau) = H(\tau) / H(\tau = 0)$$

$H(\tau_1)$, $H(\tau_2)$ are the unnormalized autocorrelation functions;

τ_1, τ_2 - the delays.

In Fig.10 the block diagram of a device for realization of the optimum leak detection algorithm is shown.

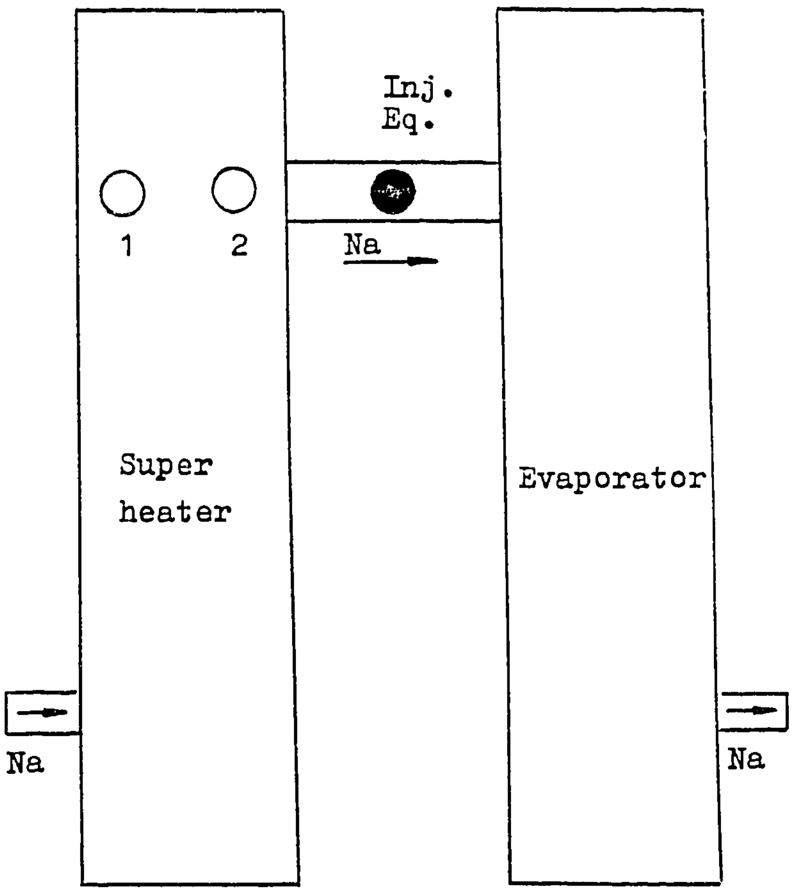

Fig.9. Diagram of sensor arrangment at SGU.

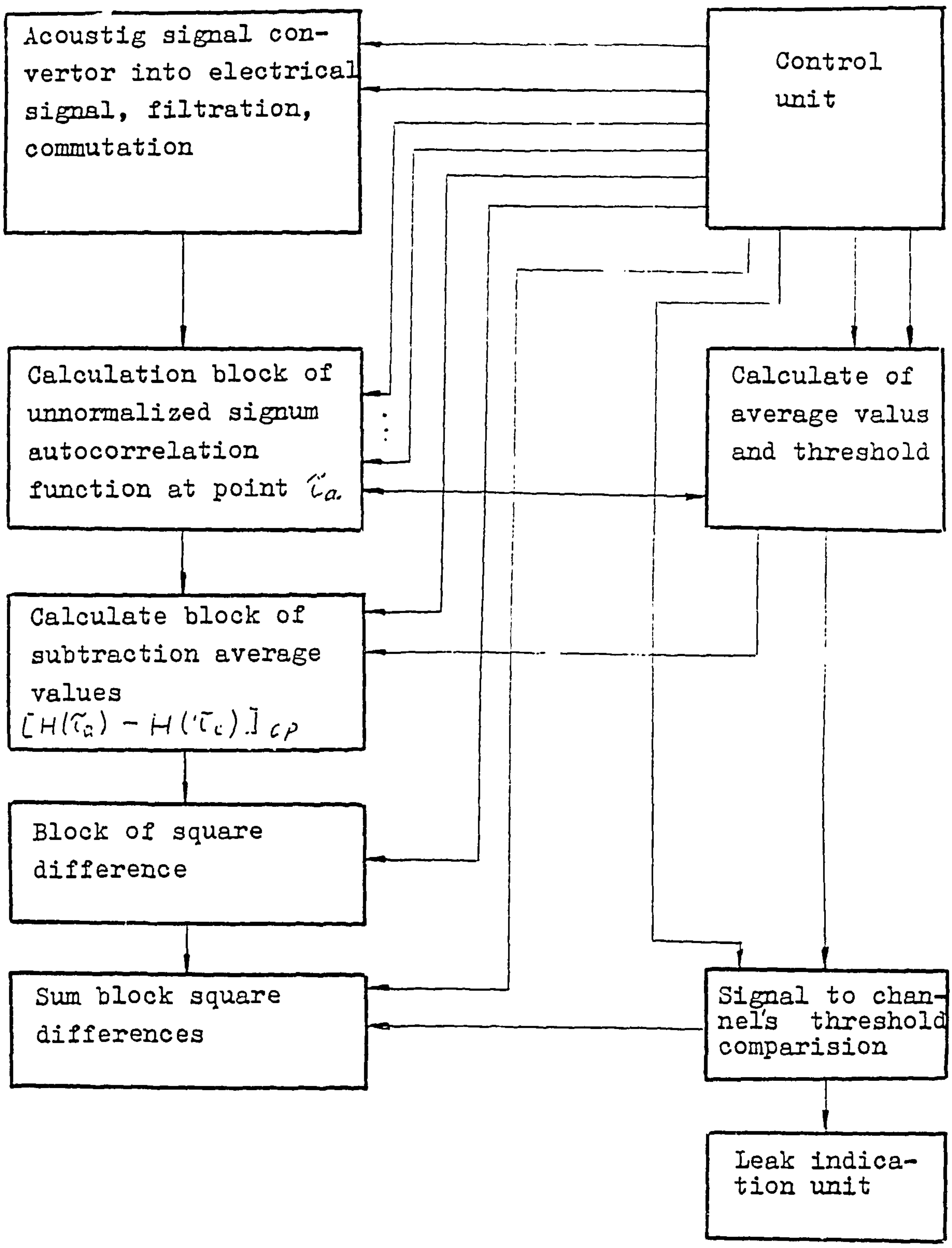

Fig.10. Block diagram of a facility for realization of optimal detection algorithm.

In a specified frequency band the signum autocorrelation function was calculated from realization of the background noise recorded by the magnitograph. Then, in the same frequency band the signum autocorrelation function from realization of the signal was determined. It is presented as a sum of the background noise and the argon-into-sodium leak signal.

In Fig.11 the relationships $\tilde{H}(\tau)$ plotted from the results of $\ddot{H}(\tau)$ measurements at ten points with an interval of second between noise realizations with and without an argon leak are presented. Channel width is 1 s. The frequency band is (20-30) kHz. The detectors are placed at a distance of 1.5 m from the injection device.

Fig.12-14 present the relationships of the same character for $\tilde{H}(\tau)$ measured from noise realization in frequency bands of (30-40) kHz, (40-50) kHz, (50-60) kHz, respectively.

From the figures it can be seen that:

- with an increase of frequencies in the analyzed band of the signals a slope of the initial section of the signum autocorrelation function is increased;

- with an increase of frequencies in the analyzed noise band the (leak signal + background)/background ratio is increased for the parameter representing the value of the signum autocorrelation function slope;

- the maximum change in the slope of the initial section of the signum autocorrelation function at a leak occurence is observed in a band of (50-60) kHz.

There were also conducted investigations on the dynamics of the leak propagation process for the parameter $\check{H}(\tau)$ in real time. With the use of the acoustic noise analyzer in real time the $\check{H}(\tau)$ values were measured and taken into the memory of the microcomputer for a noise study immediately prior to and during

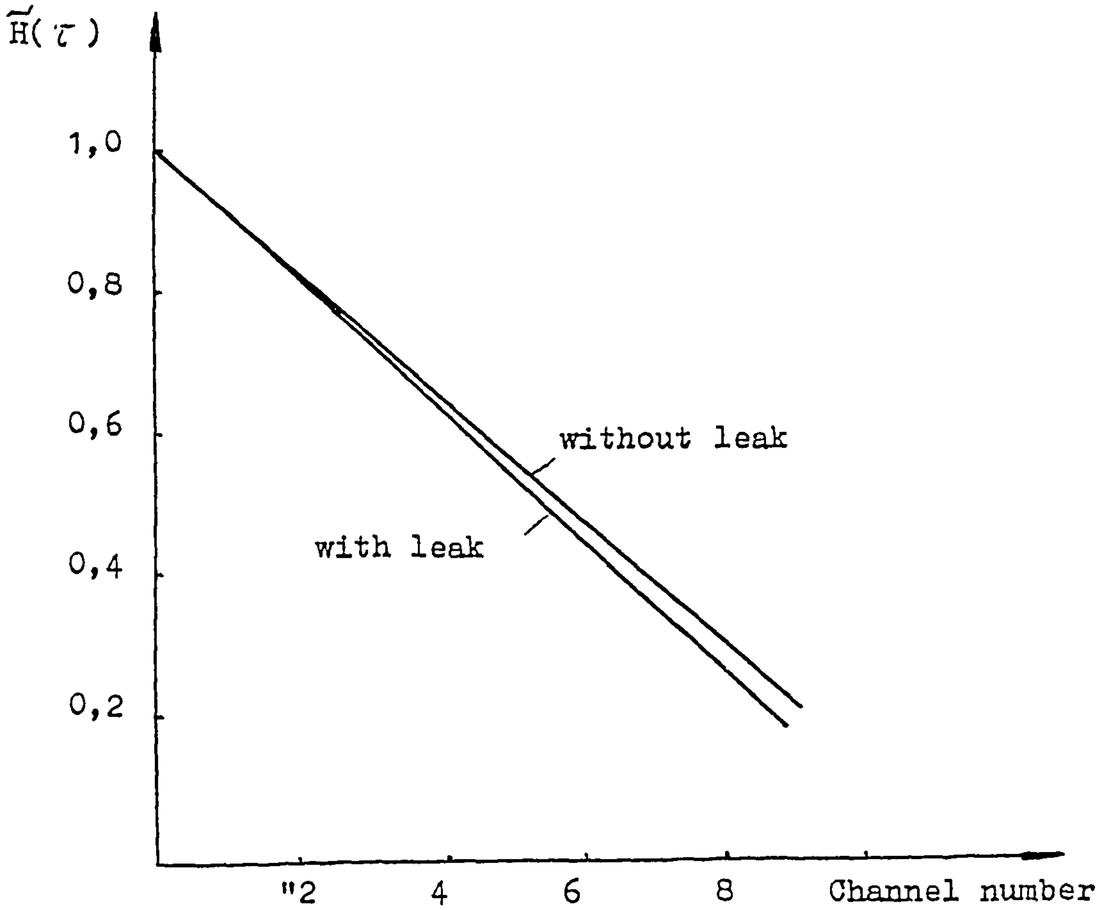

Fig.11. Signum autocorrelation function with leak and without one for frequency band (20-30 kHz).

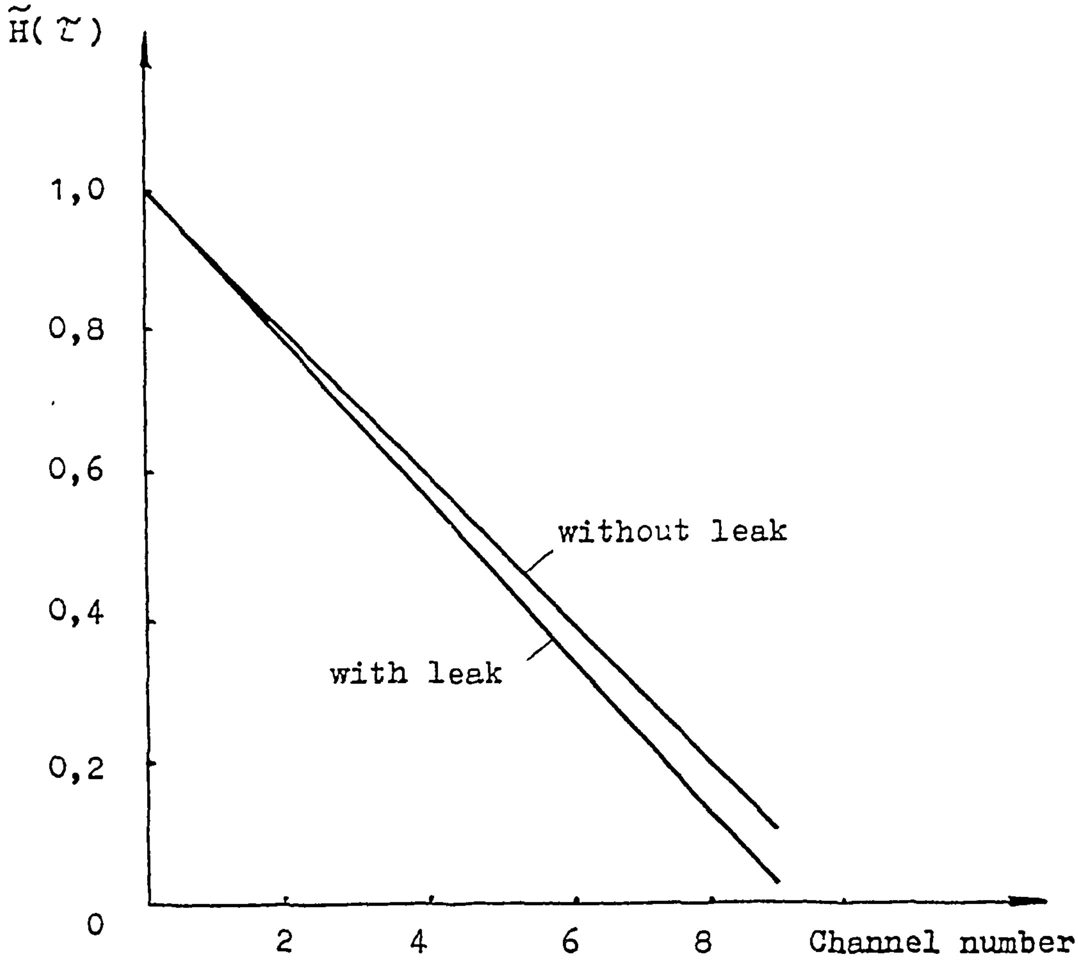

Fig. 12. Signum autocorrelation function with leak and without one for frequency band (30-40 kHz).

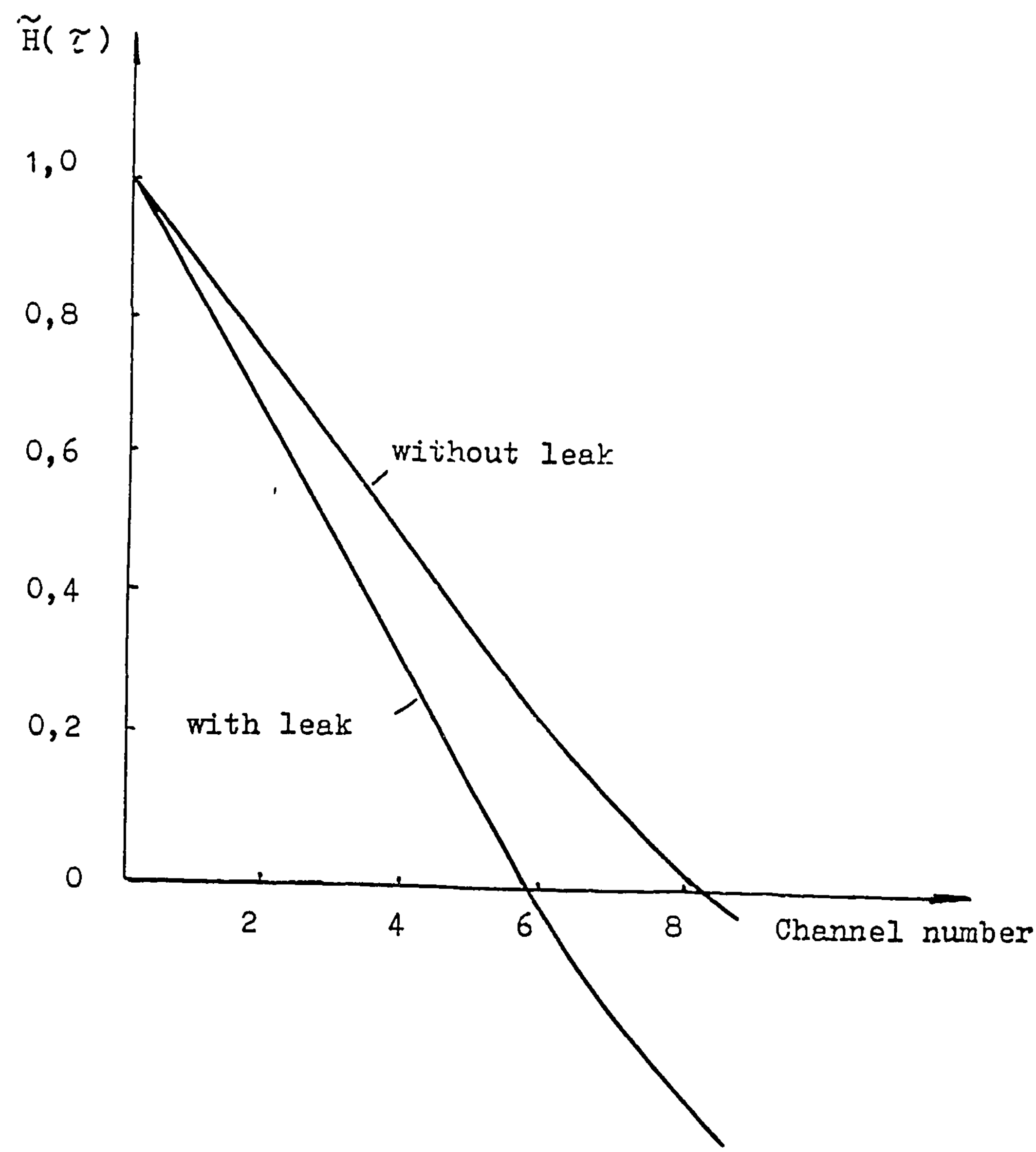

Fig.13. Signum autocorrelation function with leak and without one for frequency band (40-50 kHz).

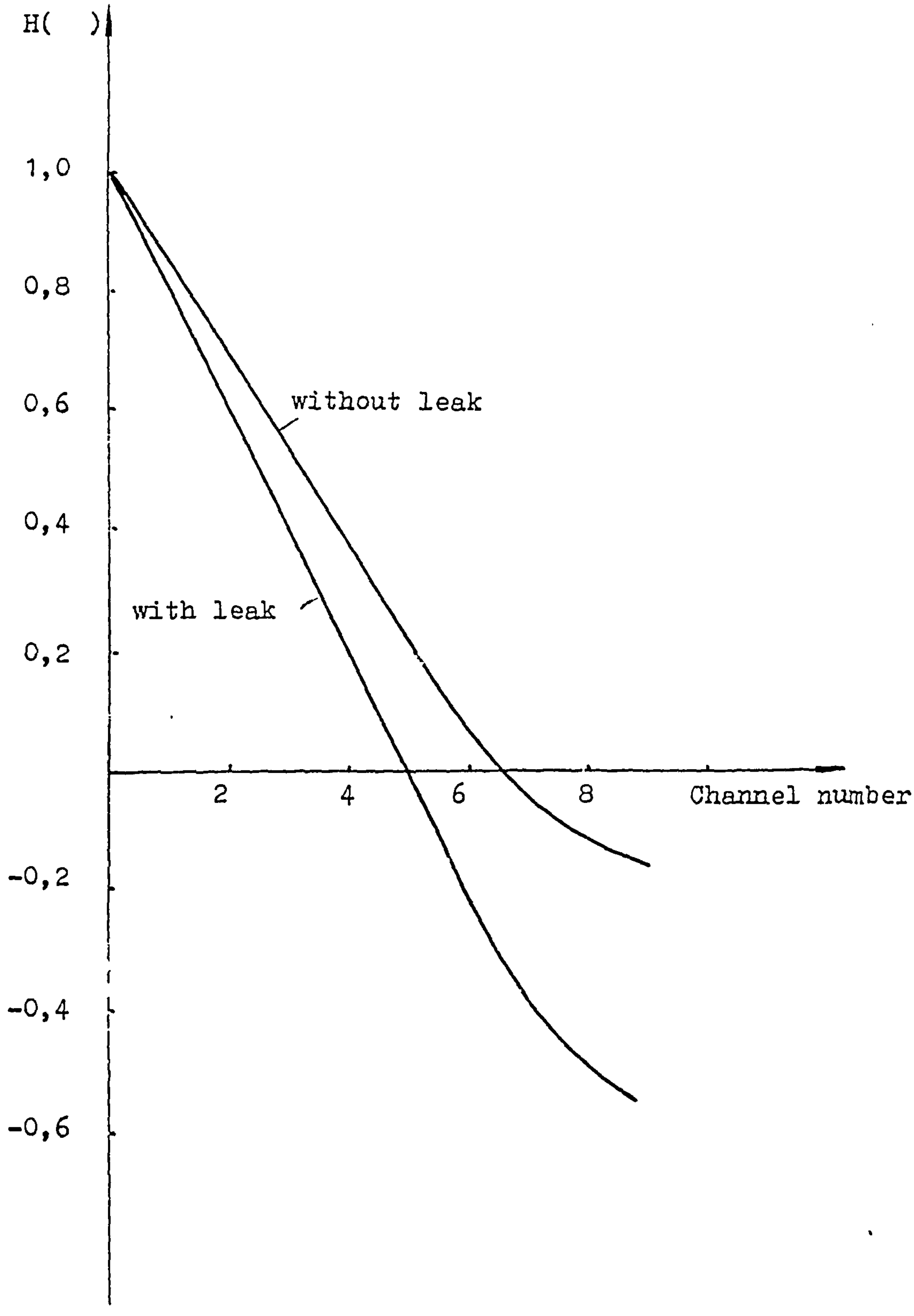

Fig.14. Signum auto correlation function with leak and without one for frequency band (50-60 kHz).

injection. Investigations were carried out on the records of noise realization made during experiments on leak modelling. In Fig.15 are presented relationships obtained for the 25 correlgrams measured and for 10 channels of $\check{H}(\tau)$. On the abscissa the correlogram number corresponding to current time is plotted. The difference between neighbouring counts is equal to the sum of times of the $\tilde{H}(\tau)$ calculation by the correlometer and of correlogram reception in the microcomputer memory. These times are equal to 200ms and 5 ms, respectively. The twelfth count corresponds to the correlogram calculated at time of argon-into-sodium leak initiation. From the figure it is seen that a sharp change of $\tilde{H}(\tau)$ occurs at argon-into-sodium leak appearance.

Experiments on the determination of the argon flow rate effect upon the $\tilde{H}(\tau)$ parameter were carried out. The signal/noise ratio for the $\check{H}(\tau)$ parameter was shown to increase with flow rate.

From the above it follows that:

The signal/noise ratio for the $\tilde{H}(\tau)$ parameter can reach a value of 10 and more and this ratio is a maximum in the region of negative values of $\tilde{H}(\tau)$.

- To increase the signal/noise ratio one should use the high-frequency filter with a cutoff frequency of 10 kHz with high (60 db) suppression outside the operating band.
- An effective frequency band for investogation is that of (50-60) kHz.

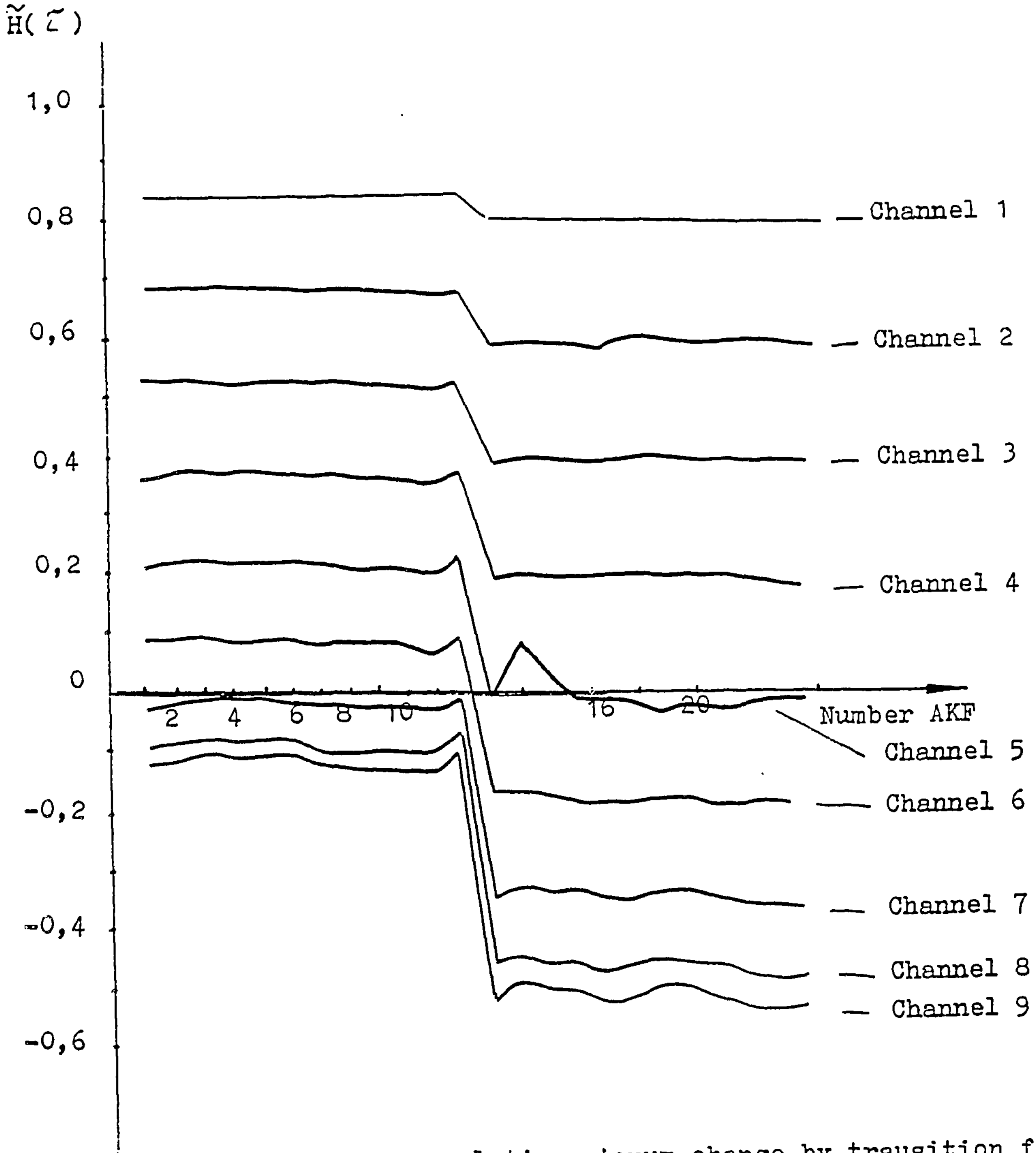

Fig.15. Autocorrelation signum change by trausition from background noise without leak to background with leak.

REFERENCES

1. Yugay V.S., Masagutov R.F., Kozlov F.A. Investigation of Acoustic Effects at water-inti-sodium leak, Atomnay energiya, 1975, v.54, issue 3.

2. Golushko V.V., Dunayev V.S., Kuznetsov A.M. Principlos of construction of system for leak detection in steam generators by acoustic method. Preprint-33(645) NRRI, Dimitrovgrad, 1984.

3. Petrenko A.A., Shchekotov V.G., Authoris Certificate. SU 1029736, G01N29/02.

4. Proceeding Smorn-V Conference, 12-16 oct., 1987., Munich, FRG. 5. Petrenko A.A., Sotnikov P.A. Author's Certificate, SU, 961480.