New Folder Name Intermediate Report

Physikalisch-Technische Bundesanstalt
Laboratorium für Vakuumphysik

Intermediate Report

Pressure pulses
(Activities to detect pressure pulses caused by UHV vacuum pumps)

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Summary

For the development of gravitation wave detectors stability of pressure in the vacuum system is an important factor for the detection limit of gravitational waves.
The equipment for the detection of pressure pulses in the millisecond range in a volume of 50 l was developed in the 'Laboratorium für Vakuumphysik' of the Physikalisch-Technische Bundesanstalt (PTB), Germany.

The limit of detectable pulses at a working pressure of 10^{-8} mbar is $2 \cdot 10^{-11}$ mbar.
The present detection level is limited mainly by pressure fluctuations of the order of $\pm 1.5 \cdot 10^{-11}$ mbar. The reasons for these fluctuations are yet unknown.

Pressure pulses probably caused by the test ion pump were in the order of $2 \ldots 5 \cdot 10^{-10}$ mbar corresponding to gas bursts of $1 \ldots 2.5 \cdot 10^{-8}$ mbar·l.
The rise time in the given volume was about $5.5 \cdot 10^{-11}$ mbar / ms.

The work will be continued with the investigation of various types of UHV pumps to characterize the short time pressure behavior using the equipment described in this paper.
In addition we will continue our efforts to improve the measuring capabilities.

1. Introduction

For the realization of highly sensitive gravitational wave detectors long baseline optical interferometers are being planned. These interferometers with arm lengths of several kilometers will operate under ultra high vacuum (UHV) conditions at pressures of typically 10^{-8} mbar. As optical interferometers are measuring changes of the optical path length, they are sensitive of pressure pulses in the vacuum tank. A millisecond pressure pulse of 10^{-12} mbar in a 1m segment of the tank may cause interferences like a gravitational wave.

UHV pumps are suspected to produce such pressure pulses e.g. by gas bursts in the ms range. It is our task to investigate various types of UHV pumps with regard to causing pressure pulses.

2. Experimental

2.1. Vacuum equipment

A 400 l/s Varian ion pump (triode type) was used for the first investigations.
The vacuum scheme is shown in Fig. 1.
The pump P is connected to the main vessel which has two symmetrically arranged ion gauge heads IGH for coincidence measurements. The gauges are of normal Bayard-Alpert type. The system is evacuated with an auxiliary pump system APS to reach the start pressure of the ion pump. APS is also used during bakeout. The ultimate pressure is approximately 10^{-9} mbar. By letting gas into the volume with the variable valve VV we generate stable working pressures of $1 \cdot 10^{-8}$ mbar (H_2). With the piezo-electrical valve PV it is possible to generate small pressure pulses of 1% of the working pressure for testing of the electrical equipment and the software. The quadruple mass spectrometer MS was used for gas analysis.
The total volume is approximately 50 l.

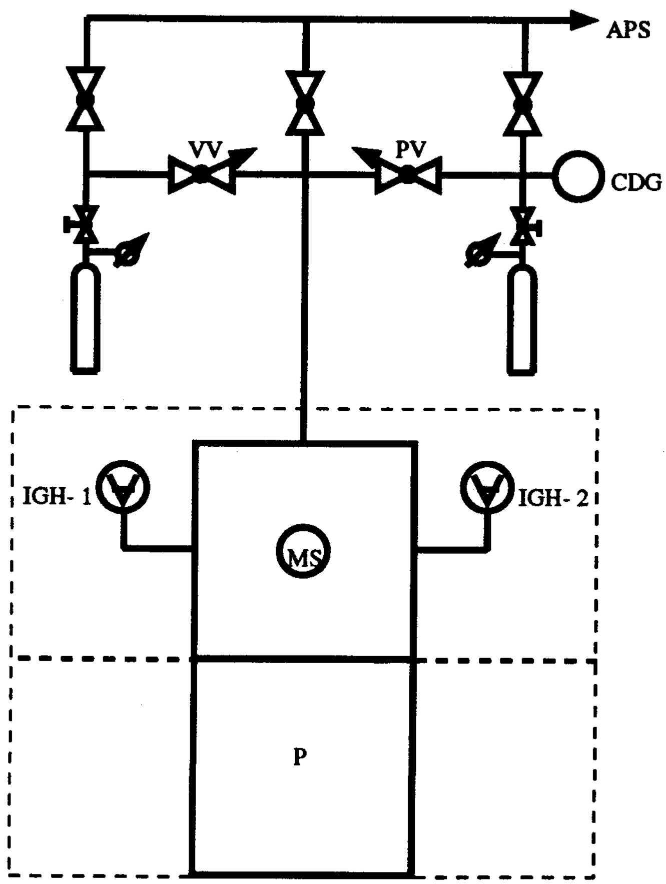


Fig. 1, Vacuum scheme

2.2. Electrical equipment

- In the beginning of the investigations:
  - — two ion gauges IM 520 from Leybold with heads of extractor type
  - — two current amplifiers Keithley 428
  - — one Digital Multi Meter (DMM) Keithley 194 A (two channels, 16 bit resolution, 100,000 samples/s, memory for 30,000 values/channel)

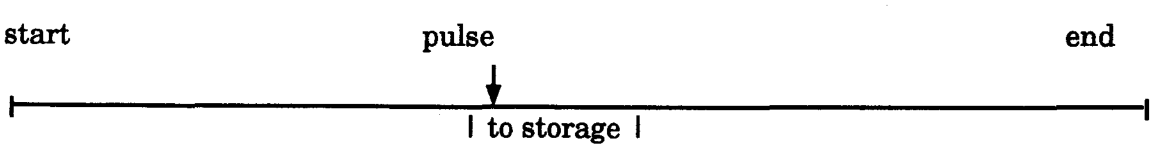
- Now:
  - — two Ion gauge heads of Bayard-Alpert type
  - — specially stabilized power supplies
  - — two well shielded and battery powered current amplifiers (own development)
  - — the DMM (see above)
  - — controller for the piezo-electrical valve
- in the future
  - — improved current amplifiers
  - — improved power supplies with shielded batteries

2.3. Storage and pre-analysis of data

All measurements were carried out at a working pressure of approximately $1 \cdot 10^{-8}$ mbar with a data acquisition of the ion collector currents of 1000 samples/s in two channels to allow coincidence measurements.
The control program can select

- the range of the DMM (separate for each channel)
- the channel which values are to be pre-analyzed
- the number of samples/s
- the number of data values to be stored
- the number of data values before and after an 'event' (see Figure).
- the threshold pressure when a signal will be stored (deviation from the mean square)
- the number of cycle's

Measurement cycle: (e.g. 30 s)



When a cycle is finished all values (from the two channels) will be transferred to the computer and one channel will be pre-analyzed.

The pre-analysis will be carried out in the following manner:

- calculation of the mean square of the cycle
- examination of all data points for 'events'. (If two consecutive data points deviate from the mean by more than a preset value (typically >= 1.05 of the mean) an 'event' will be diagnosed.)

If an event is detected, simultaneous data points from both channels will be stored (see Fig. above).

After this procedure a new cycle will be started.

The time for the data transfer, pre-analyzation and storage is 2...6 s.

2.4. Gauges and gauge control

2.4.1. The DMM

The noise limit of the DMM (input shielded) in the 3 V range is approximately ± 0.4 mV (or $2 \cdot 10^{-4}$ at 2 V, see Fig. 2) for the extreme values.

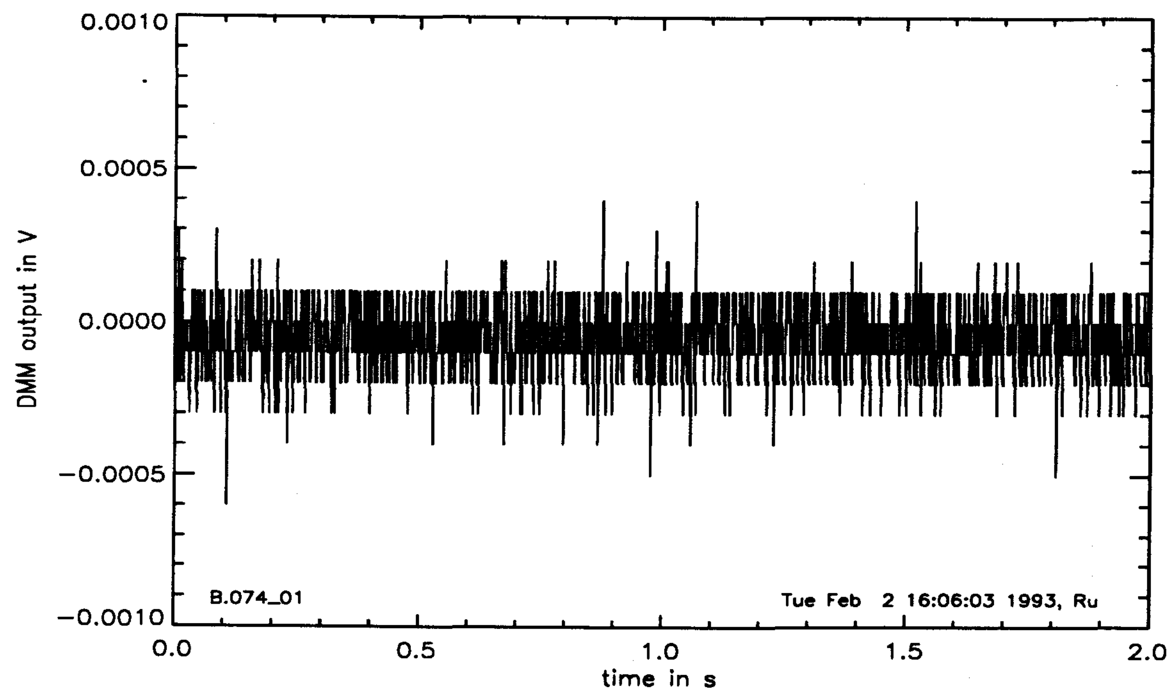


Fig. 2, noise of DMM, input open, shielded

2.4.2. The power supplies

We started the investigations with Leybold hot cathode ion gauge controllers IM 520 for the vacuum measurements. The IM 520 caused - without emission - a mains hum of ± 15 mV at the output of the current amplifier (see Fig. 3), what for general pressure measurements this is without significance.
If the emission is 'on' the mains hum is 3% of the signal (see Fig. 4).

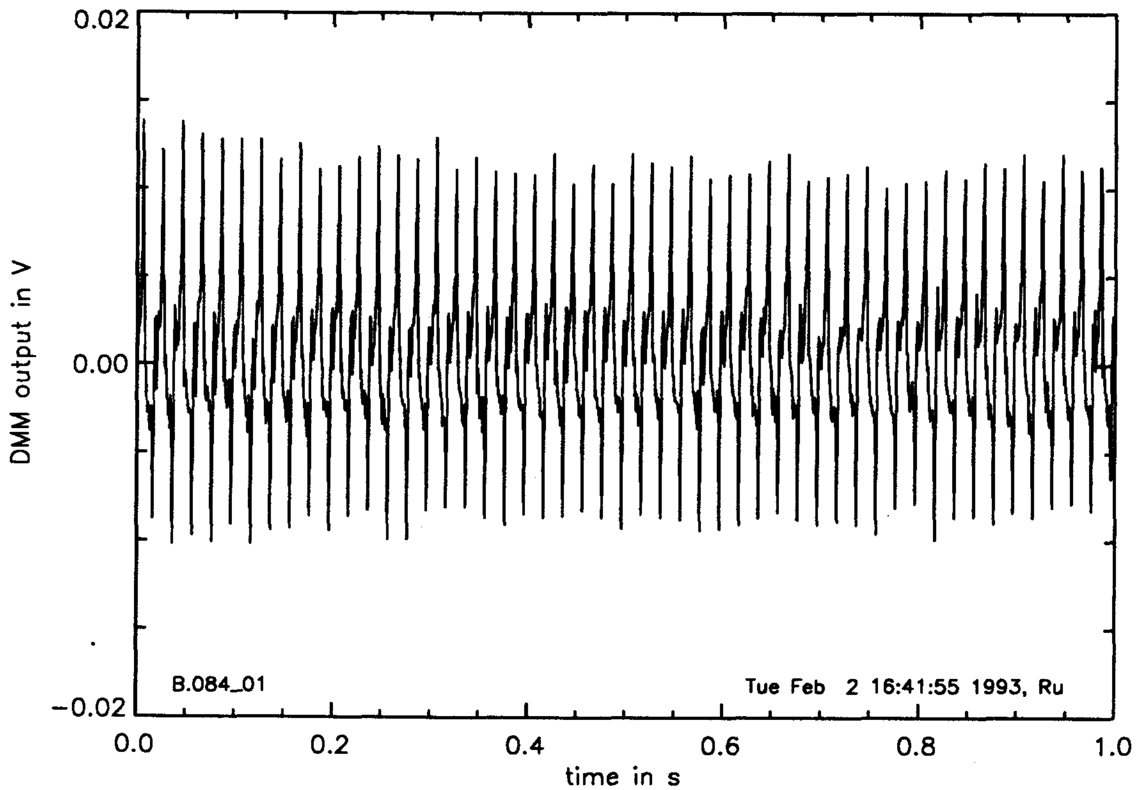


Fig. 3, mains hum of IM 520 without emission

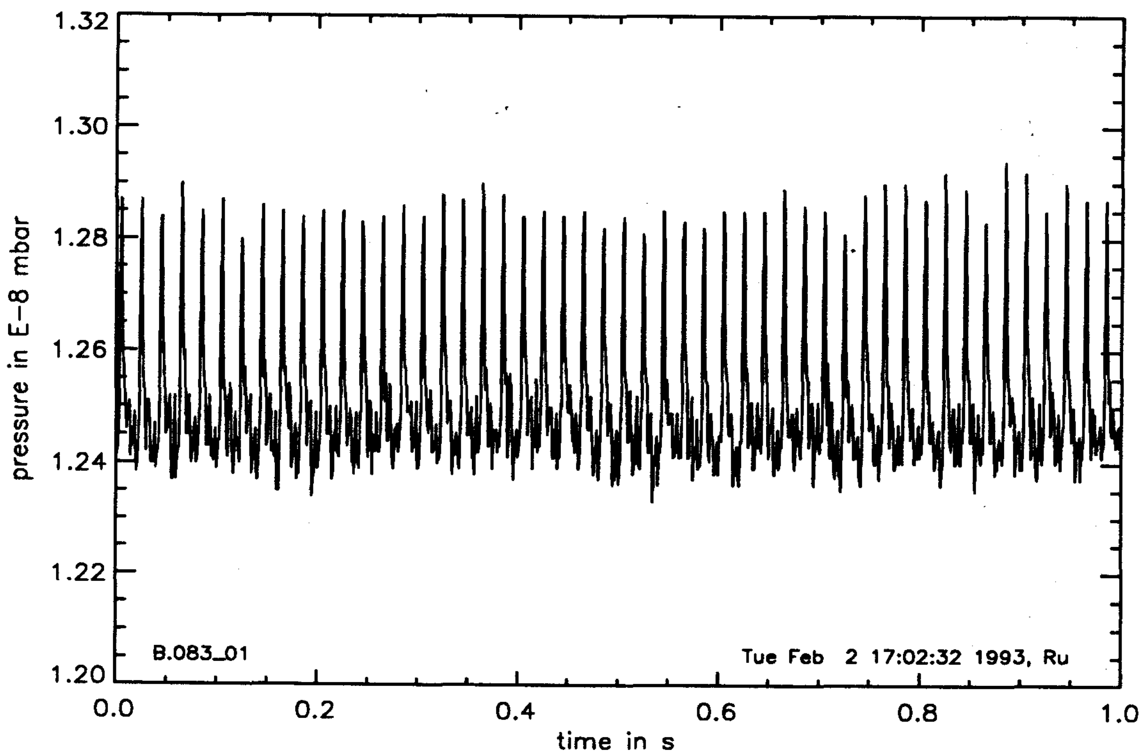


Fig. 4, mains hum of IM 520, emission 'on'

For the measurement of pressure pulses therefor the IM 520 gauge controllers were replaced by individual, highly stable DC-power supplies.

2.4.3. The current amplifiers

In the beginning Keithley 428 current amplifiers were used. Later on, better results were obtained with an amplifier developed in our group. These amplifiers have a very low noise level. Power is provided by two shielded batteries. The amplifiers are directly mounted on the ion gauge heads. Noise limit is $1.5 \cdot 10^{-13}$A.

2.4.4. Procedures to minimize noise

For a lower noise level the following improvements were carried out:

- development of a specially shielded current amplifier
- substitution of the commercial ion gauge power supplies by special highly stable DC power supplies
- substitution of the gauge heads of extractor type by heads of Bayard-Alpert type (with higher sensitivity, emission current 10 mA).

3. Reference measurements

After these improvements the noise level was approximately ± 0.35% as shown in Fig. 5. If no data processing as described below is used, the limit of detectable events would be > 0.4% (at 10^{-8} mbar level).

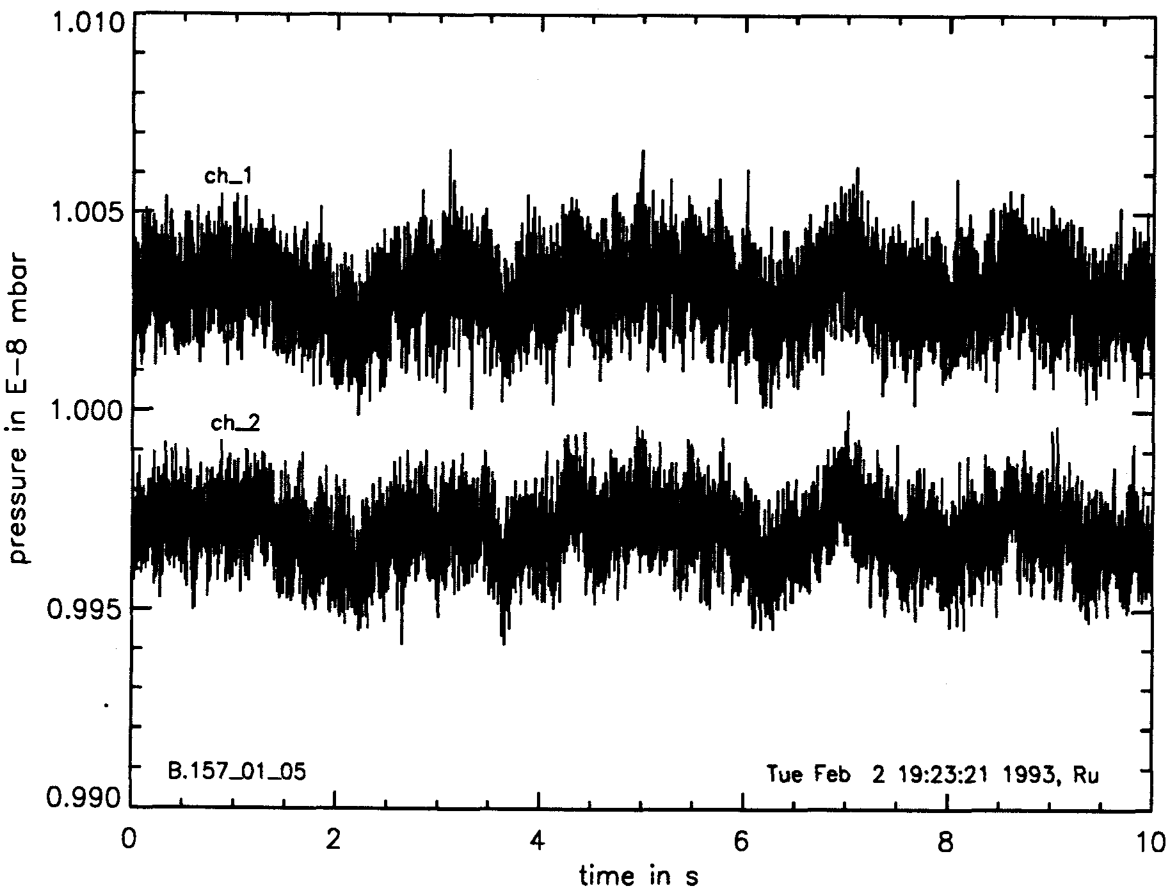


Fig 5, noise in the two channels

The result of a fourier analysis and a noise reduction by suppressing higher frequencies shows that fluctuations exist in both channels which are nearly identical. This is typical for our measurements. The fluctuations are approximately ± 0.15 % (Fig. 6).
This limits detectable events to > 0.2% (at 10-8 mbar level).

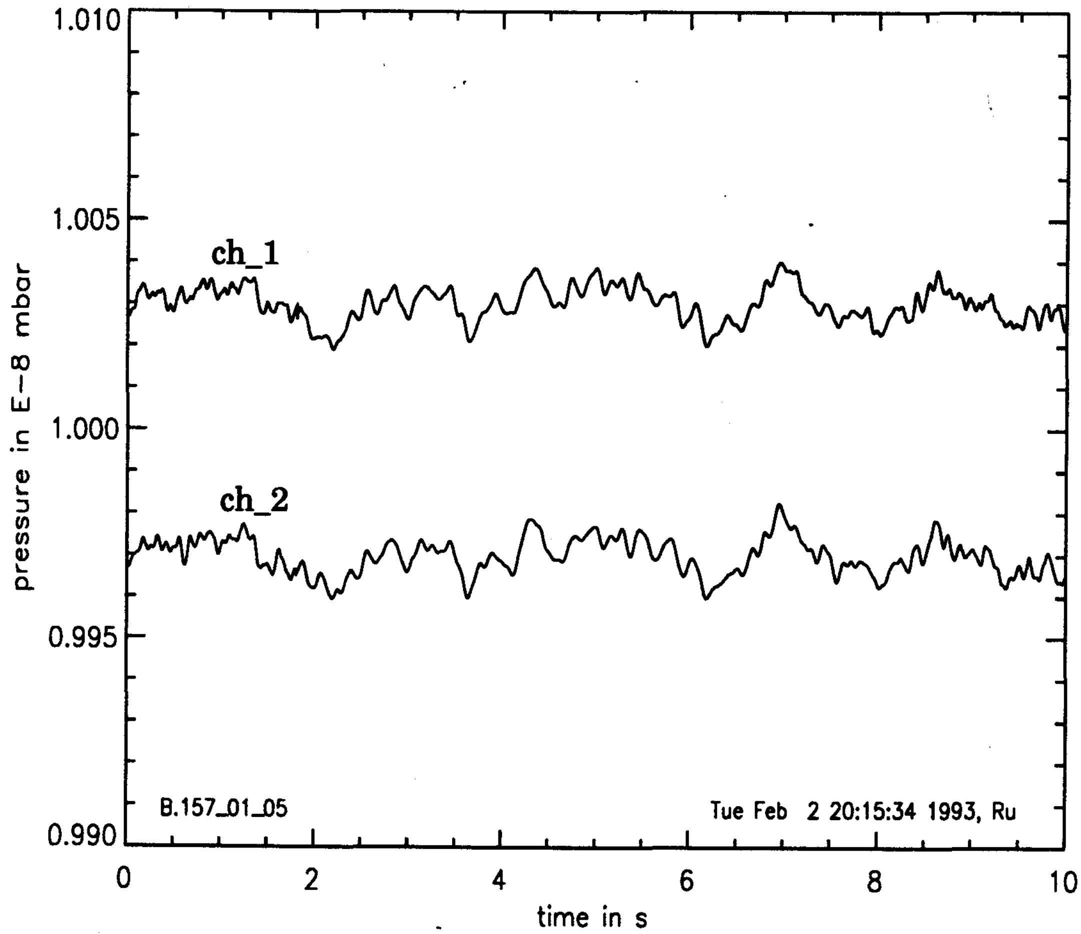


Fig. 6, like Fig. 5 but fourier analyzed and high frequency noise suppressed

In a next step we investigated the measurement equipment (and the software) with generated pressure pulses. The piezo-electric valve was opened for 15 ms. Fig. 7 shows the response of the two gauges. Two curves show the original values. Another two curves are smoothed by fourier analysis.

The peak height is approximately 0.8% of the working pressure (10^{-8} mbar) corresponding to $8{\cdot}10^{-11}$ mbar. Fig. 8 shows the pulse in detail. We can see that the pulse maximum is reached in approximately 180 ms.

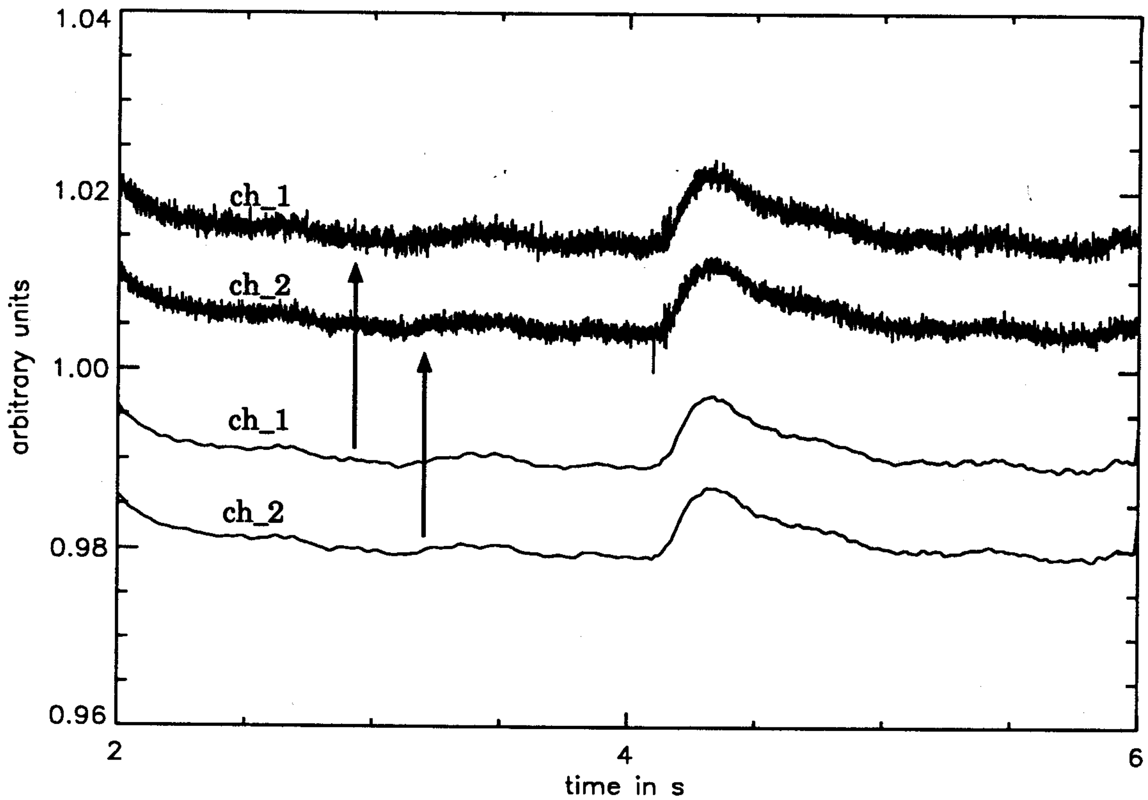


Fig. 7, generated pressure pulse

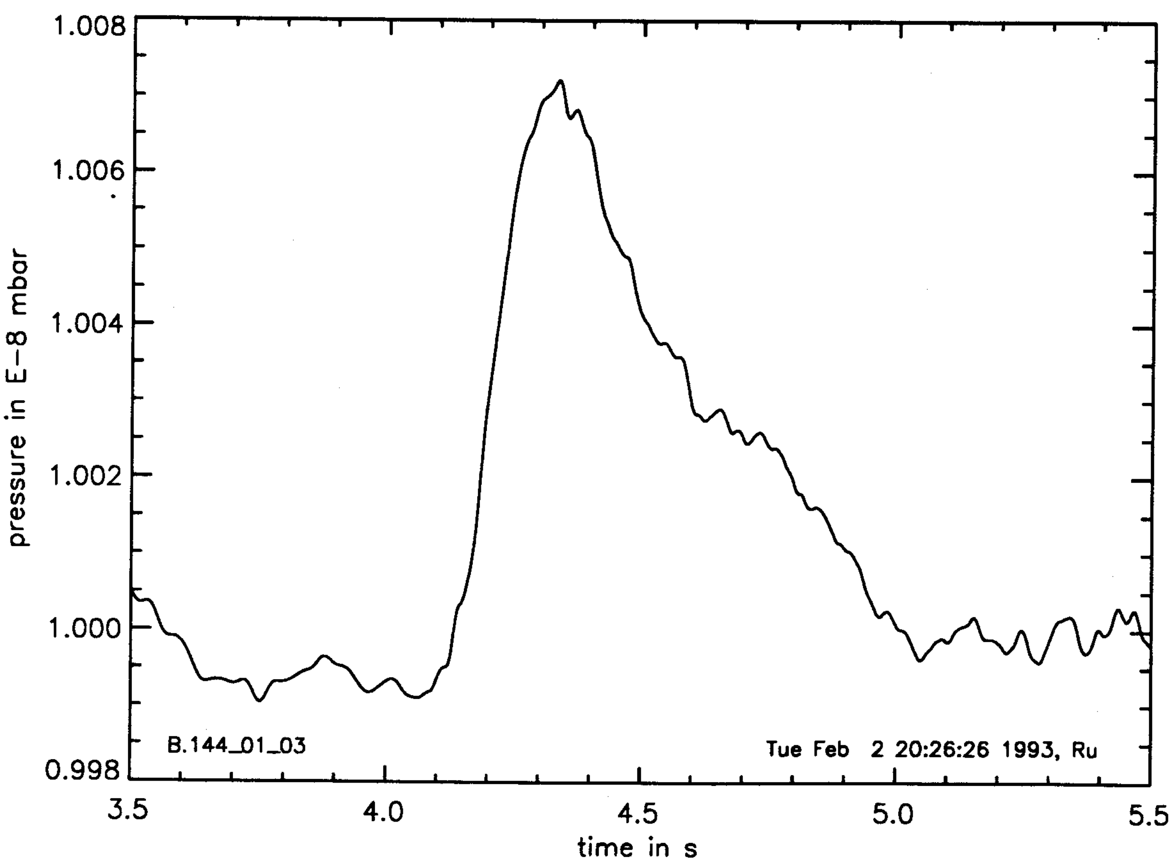


Fig. 8, generated pressure pulse, detailed

4. Results with the test ion pump

4.1. Pulses

Mostly, measurements were taken at night (to reduce mechanical vibrations). One measurement period (~ 10 h) had approximately 1000 cycles with a measurement time of 30 s each. The time between two cycles is approximately 3 s. In each 10 hours measurement period we found typically 2...3 pressure pulses probably caused by the ion pump. The peak height is in typically 2...5% corresponding to gas bursts of $1...2.5 \cdot 10^{-8}$ mbar·l. Fig. 9 shows a typical pressure pulse.
The pressure rise time is approximately 30 ms, shown in Fig. 10.

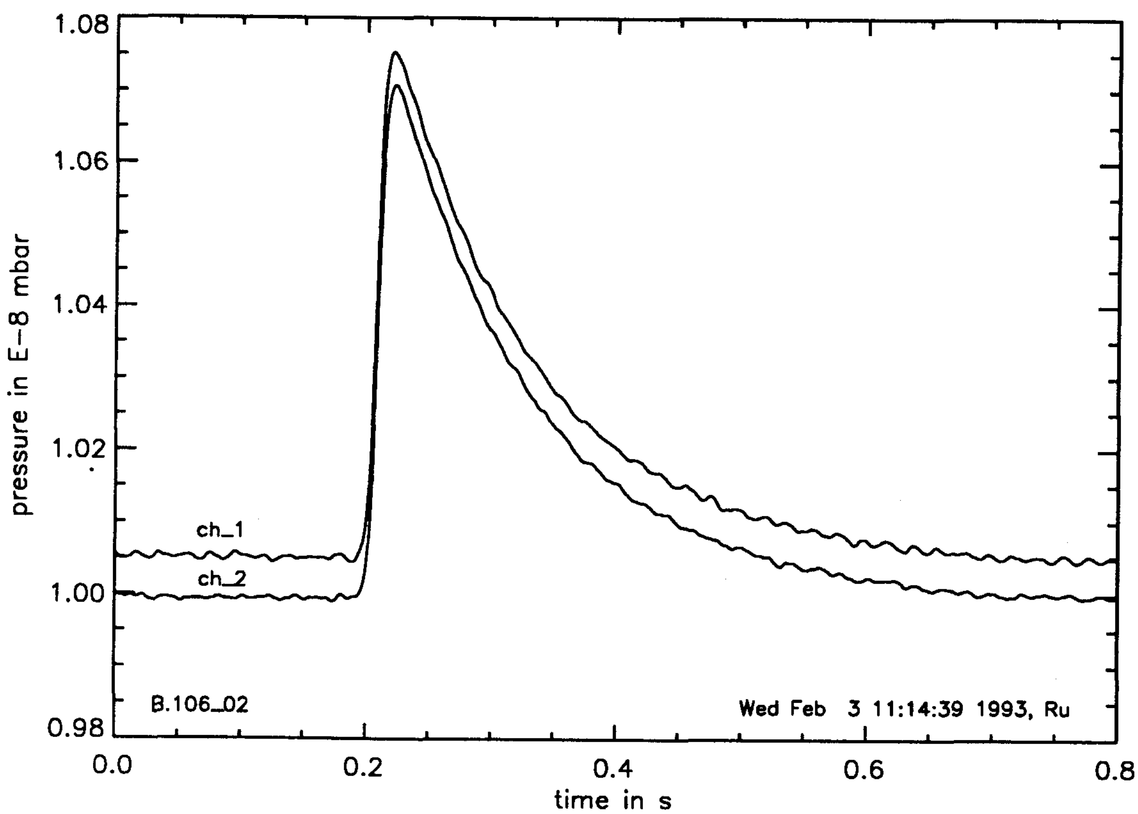


Fig. 9, typical pressure pulse

The manual extrapolation to the zero (onset) time of the pulse (see Fig. 11) shows that the pulse height was $0.1 \cdot 10^{-8}$ mbar corresponding to $5 \cdot 10^{-8}$ mbar·l. The rise time was about $5.5 \cdot 10^{-11}$ mbar/ms.

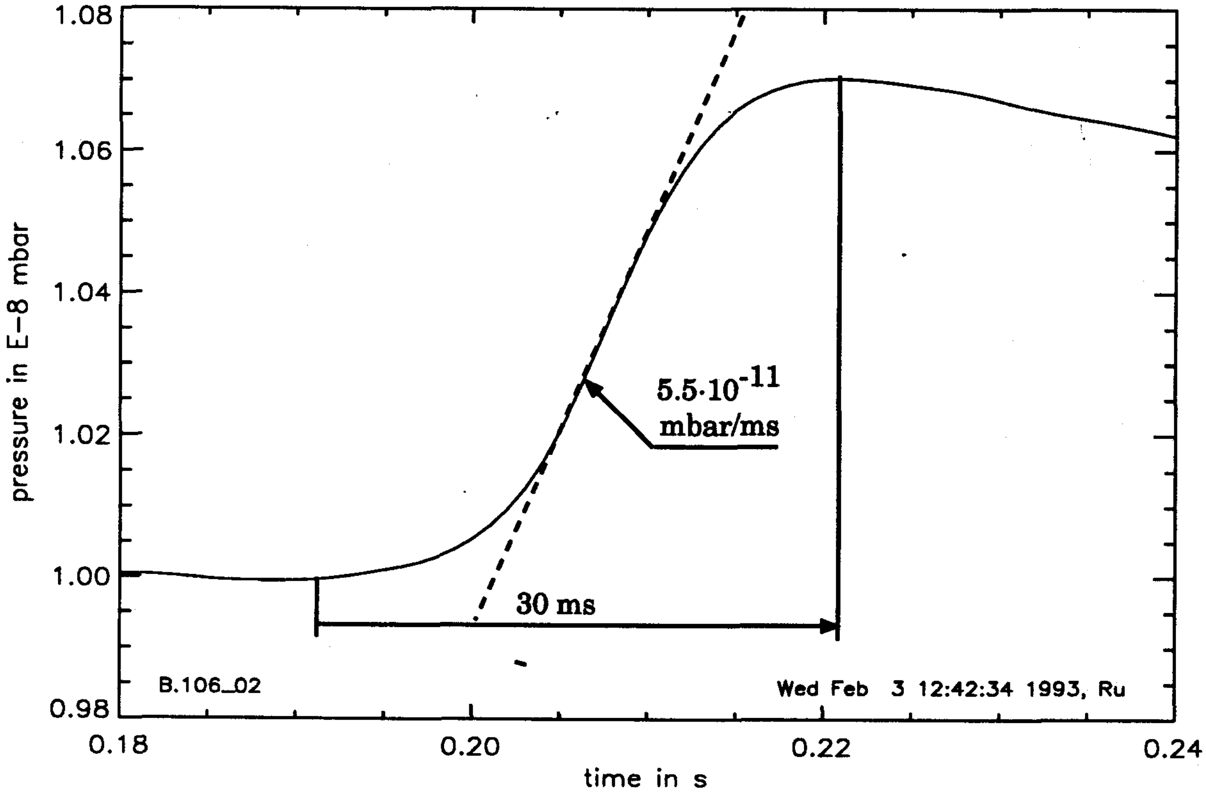


Fig. 10, increase time of a typical pressure pulse

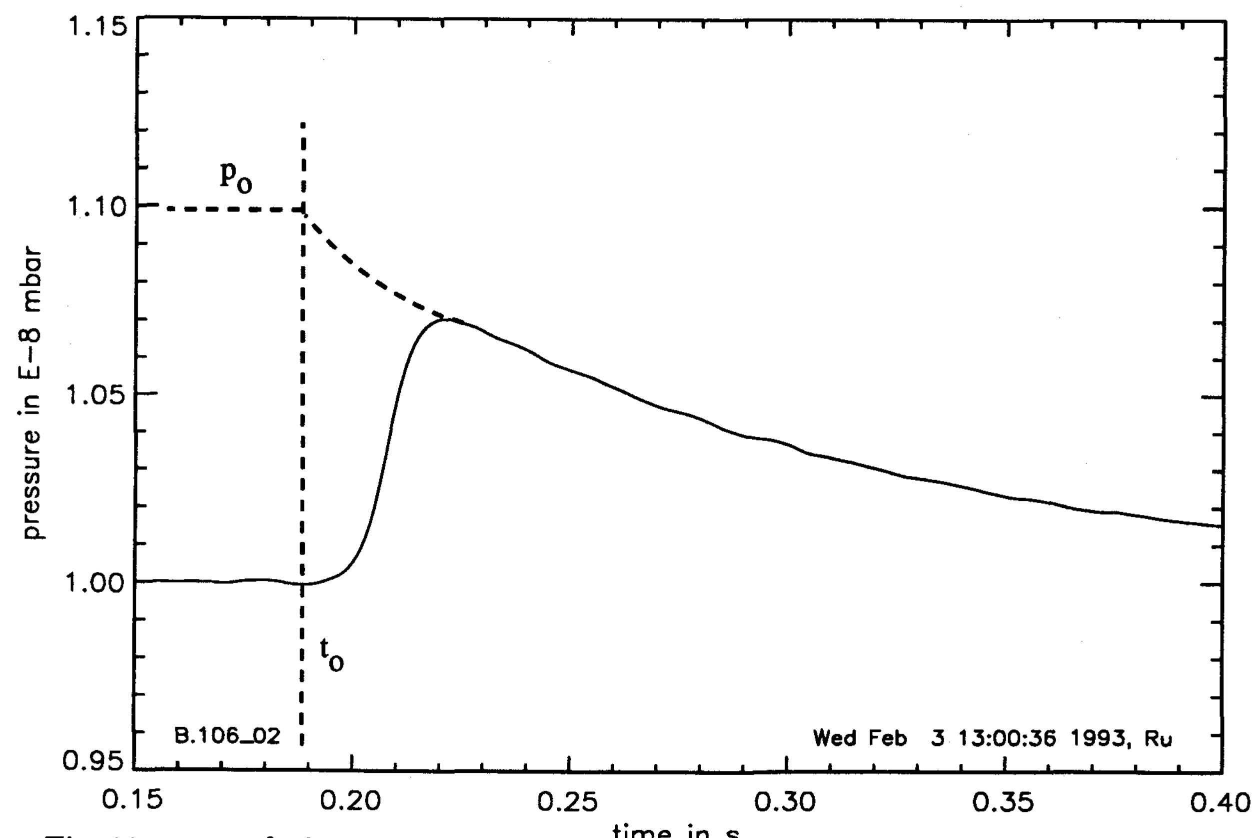


Fig. 11, extrapolation to zero time

The peak height can also be estimated by a calculated fit.
At the time t_0 the pressure p_t jumps from p_w to $p_w + p_0$.
For $t > t_0$, p_t can be described by

$$p_t = p_o \cdot exp[\, b \cdot (t_o - t)\,] + p_w$$

with b the relaxation coefficient and
p_w the working pressure at $t < t_0$.

This equation fits well the experimental results.

With

$$p_t - p_w = p_0 \cdot exp[\, b \cdot (t_o - t)]$$

and normalizing by dividing with p_1 = 1 mbar we obtain the dimensionless equation

$$\ln\left(\frac{p_t - p_w}{p_1}\right) = \ln\left(\frac{p_0}{p_1}\right) + b \cdot (t_0 - t)$$

This is a equation of the form

$$y = a + b \cdot x$$

which can be easily fitted by linear regression.

After calculating the coefficients a and b we can estimate a value for the pressure at the burst time. The coefficients have the same values for all spontaneous pulses but are different for test pulses with air and for pulses produced by the gauge heads.
The coefficient b can be interpreted as the quotient of S_{eff}/V.
We think that this is also a useful treatment for the estimation of extremely high pulses (see 4.2.).

4.2. Extremely high pulses

Sporadically extremely high pulses were observed (see Fig. 12). The height of these pulses could not be measured, because the amplifiers were saturated. The peak height was estimated to $1.3 \cdot 10^{-8}$ mbar.

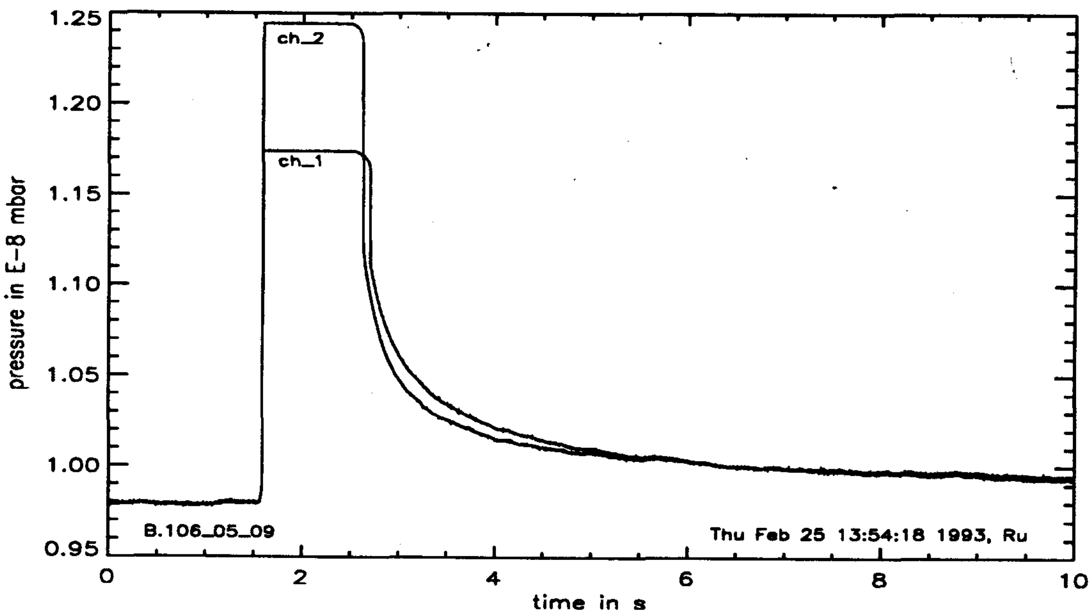


Fig. 12, extreme high pulse

4.3. Pulses caused from a gauge head

In some cases we observed pulses which are caused by gas bursts in one of the gauge heads.

Only a part of the gas quantity reached the second head ch_2 (see Fig. 13). The estamination of the pulse height at burst time by extrapolation shows a value of $1.69 \cdot 10^{-8}$ mbar for ch_1. The peak height and the rise in time of ch_2 are much smaller.

Fig. 14 shows a pulse caused by a flash (filament on) at one of the heads. The first peak is caused by particles from the surface, the second by particles from the bulk.

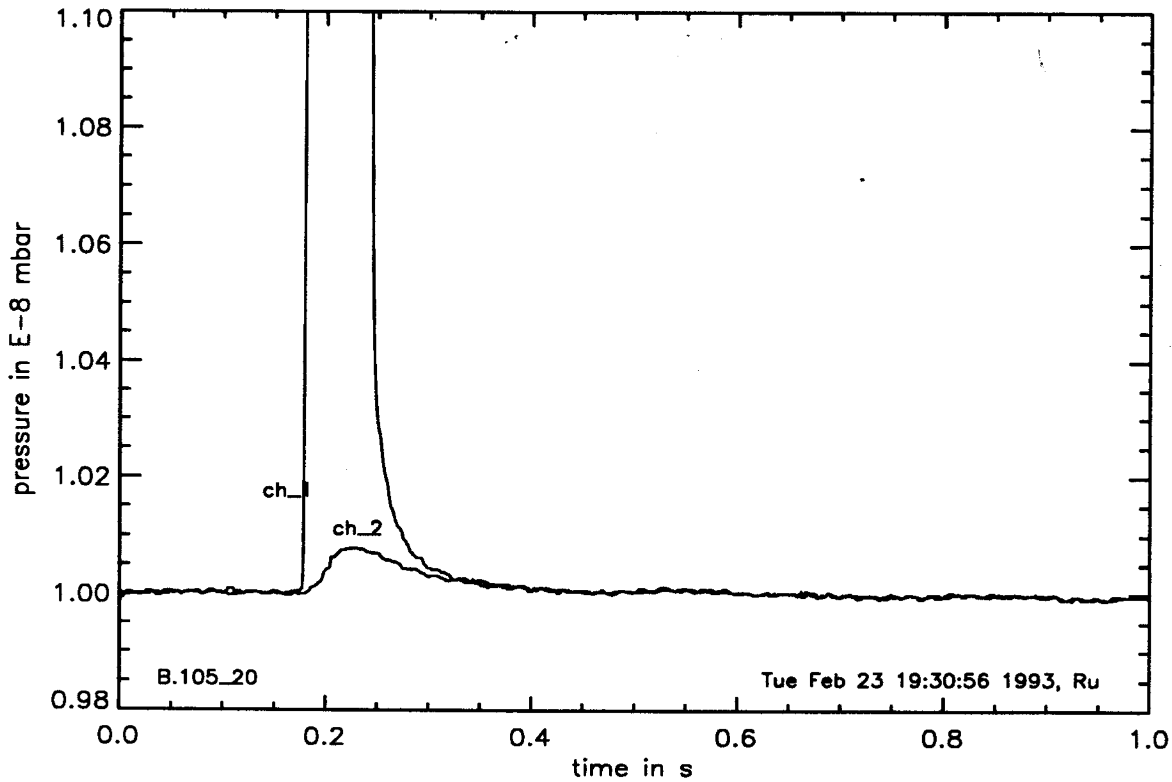


Fig. 13, pulse caused by gas burst in one of the gauge heads

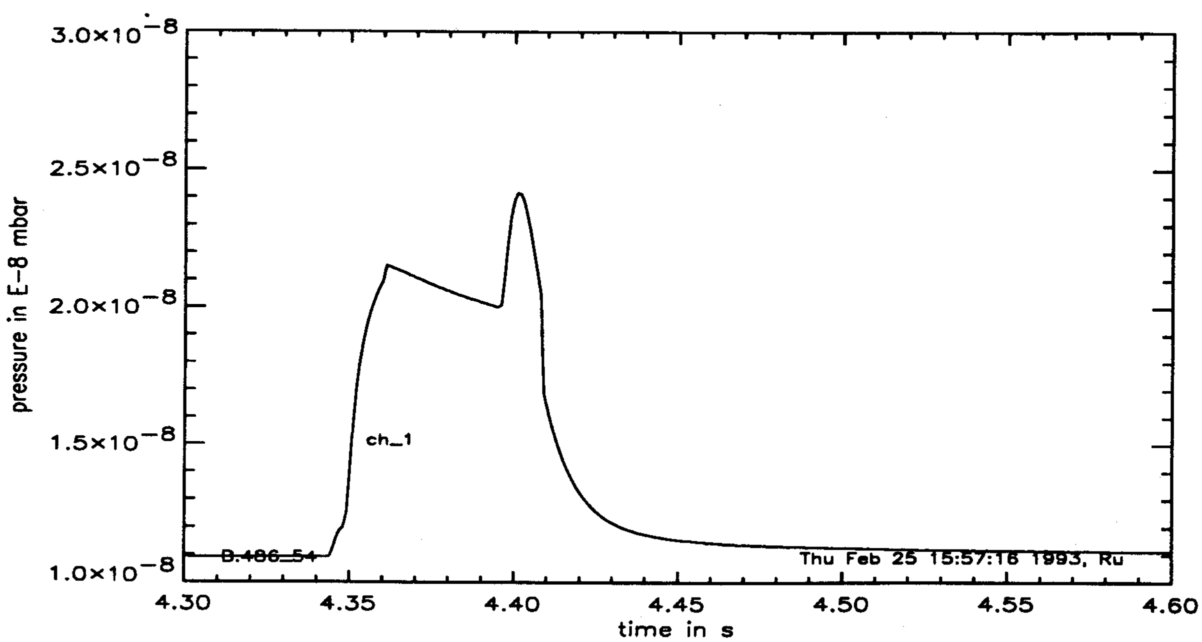


Fig. 14, filament flash

4.4. Pulses after a mechanical shock

We investigated the different parts of the equipment in respect to their response to mechanical shocks. By this way we found that after a few seconds after small mechanical strikes against the pump body gas bursts from the pump could be observed (see Fig. 15).

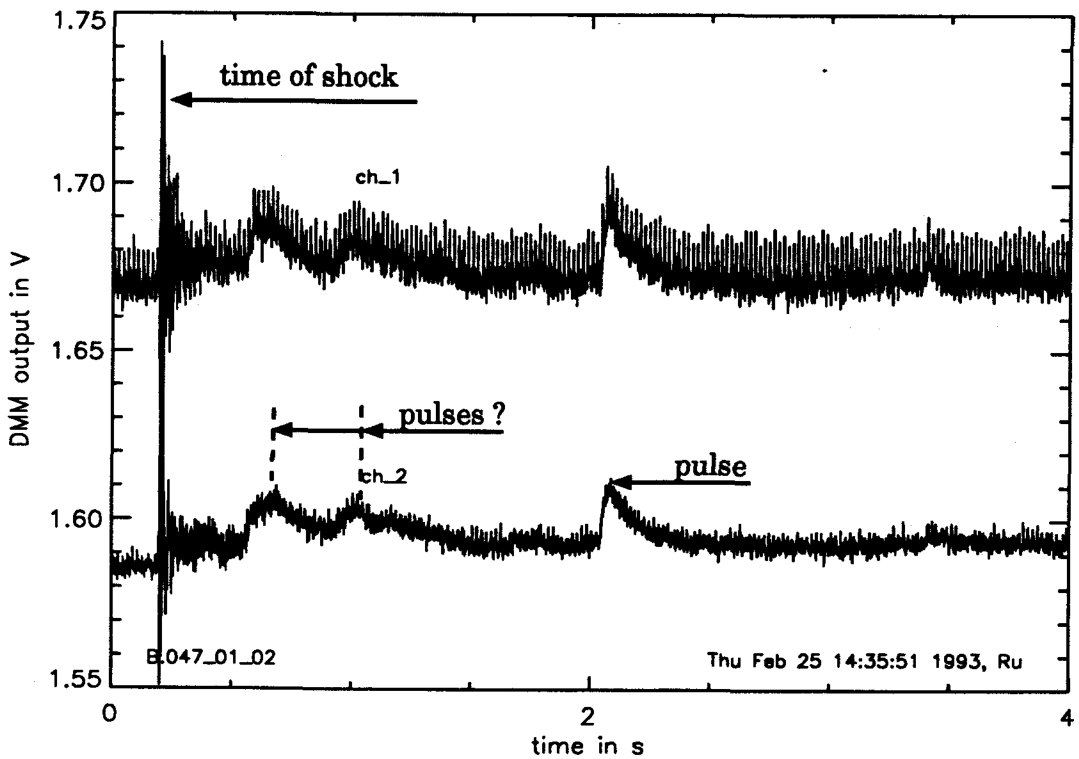


Fig. 15, pulses after a small strike against the pump body

5. Conclusions and future schedule

5.1. Conclusions

- With the present equipment and software we can detect pressure pulses $> 2 \cdot 10^{-11}$ mbar at a working pressure of $1 \cdot 10^{-8}$ mbar in a volume of 50 l.
- Test investigations with a test ion pump show: There are 2...3 pressure pulses/10 hours of a order of a few percent corresponding to gas bursts of the order of $1...2.5 \cdot 10^{-8}$ mbar·l.
- The present detection level is limited mainly by pressure fluctuations of the order of $1.5 \cdot 10^{-11}$ mbar. The reasons are (yet) unknown.
- We will now start to investigate various types of UHV pumps to characterize the short time pressure behavior using the equipment described in this paper.
- In addition we will continue our efforts to improve our measuring capabilities

5.2. Schedule

- 01/03/93 ... 30/06/93 Investigation of a Turbo pump
- 30/06/93 Intermediate report
- 01/08/93 ... 30/09/93 Investigation of a NEG pump
- 31/10/93 Intermediate report