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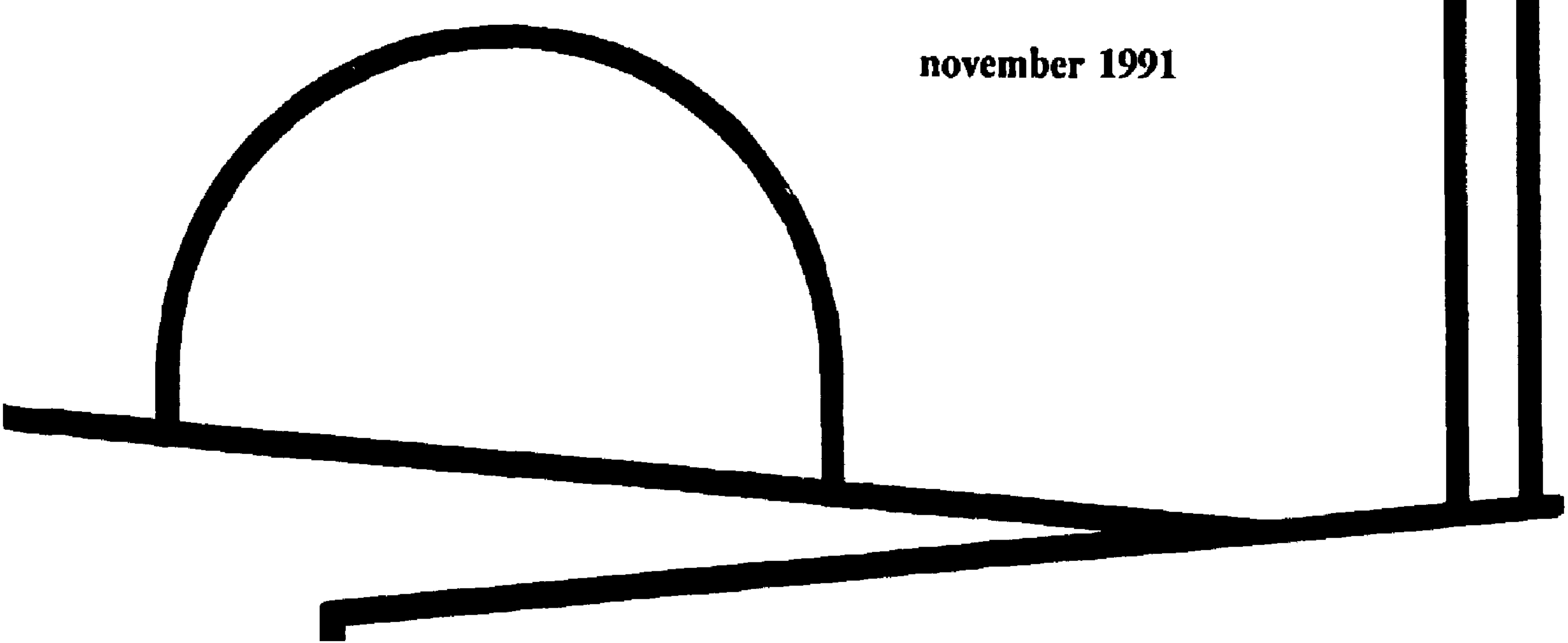


NEUTRON REFLECTOMETRY WITH ROG AND MECHANICAL VIBRATIONS

A.A. van Well

Abstract

Specifications for the maximum level of vibrational amplitudes at the sample position of the IRI neutron reflectometer ROG are presented. The acceleration and displacement amplitudes in the reactor floor have been measured as a function of frequency. These measured values meet the ROG specifications.

CONTENTS

1. INTRODUCTION

In neutron reflectometry, the quantity of interest is the reflected intensity $R(Q)$ as a function of the wave-vector transfer $Q = (4\pi/\lambda) \sin \theta$, with λ the neutron wavelength and θ the glancing angle. Since in neutron reflectometry θ is of the order of 1 degree (17 mrad), Q can be written as $Q = 4\pi\theta/\lambda$. The resolution in Q is determined by two contributions, viz. $(\Delta Q/Q)^2 = (\Delta\lambda/\lambda)^2 + (\Delta\theta/\theta)^2$. In ROG, the wavelength resolution is equal to the time-of-flight resolution (at choice 2% or 4%). The angular resolution is determined by the geometry (the height of the two beam-defining slit diaphragms) and by the undulation of the sample surface. For liquid samples the latter is determined by the surface waves present. For accurate measurements on liquids, the intensity of the mechanical vibrations, that may cause surface waves, should be very low. In section 2 a method is described to quantify the vibration requirements. One of the sources of vibrations at the sample position, is the conduction of vibrations from the floor through the support to the sample. The actual vibration spectrum of the floor of the reactor hall at the position where ROG will be placed has been investigated. Method and results are given in section 3. Section 4 contains som concluding remarks.

2. LIQUID SURFACE WAVES

2.1. Dispersion relation

For homogeneous liquids, two types of waves can be distinguished, viz. gravitational waves and capillary waves. Displacements due to capillary waves, away from the critical point, are ~ 0.5 nm. At temperatures 1 % from the critical point, these displacements increase by an order of magnitude. In the following we will neglect the contribution of the capillary waves. The dispersion relation for gravitational waves, in the limit where the height of the liquid volume is much larger than the wavelength Λ, is given by

$$\omega(K) = \sqrt{gK} \quad , \tag{1}$$

with ω the angular frequency and $K = 2\pi/\Lambda$ the wave vector. The frequency $f = \omega/2\pi$ is then given by

$$f(\Lambda) = \sqrt{\frac{g}{2\pi\Lambda}} \quad , \tag{2}$$

with g the acceleration by gravity. In Fig. 1. this dispersion relation is shown (taking $g = 10\ \mathrm{ms}^{-2}$).

2.2. Requirements sample position ROG

The contribution to the angular resolution $\Delta\theta$, caused by surface waves is denoted $\Delta\theta_{sw}$. The requirements for all angular uncertainties in the mechanical construction of ROG is 0.1 mrad. If we consider liquids, the glancing angles will typically be taken between 10 and 30 mrad. Since in liquid surface research there is in general little structure in $R(Q)$, the experiments will be performed with a relaxed angular resolution between 5% and 10%.

The above leads to the stringent requirement, $\Delta\theta_{sw} < 10^{-4}$. If this requirement appears to be unrealistic, we will be content with the moderate requirement $\Delta\theta_{sw} < 5 \cdot 10^{-4}$.

We consider a surface wave with wavelength Λ and amplitude A. The displacement d is

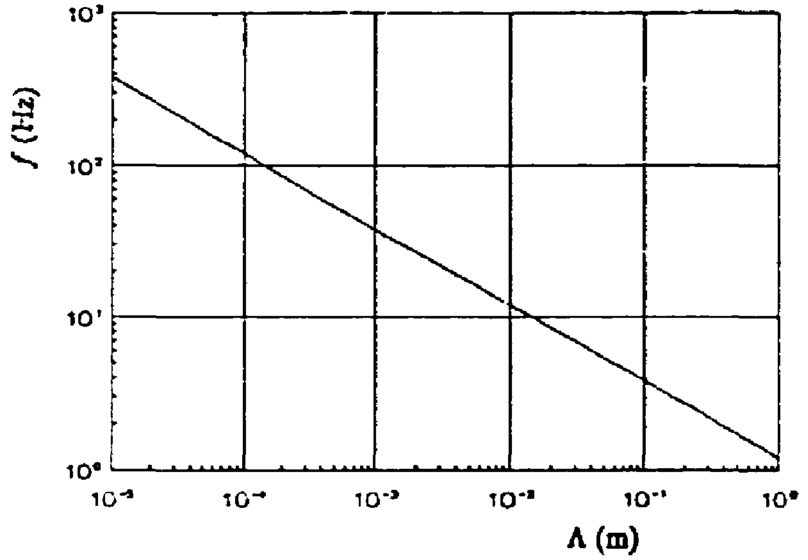


Figure 1. *Dispersion relation of gravitational surface waves.*

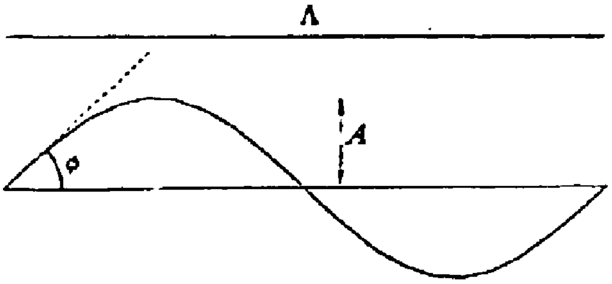


Figure 2. *Surface wave with wavelength Λ and amplitude A.*

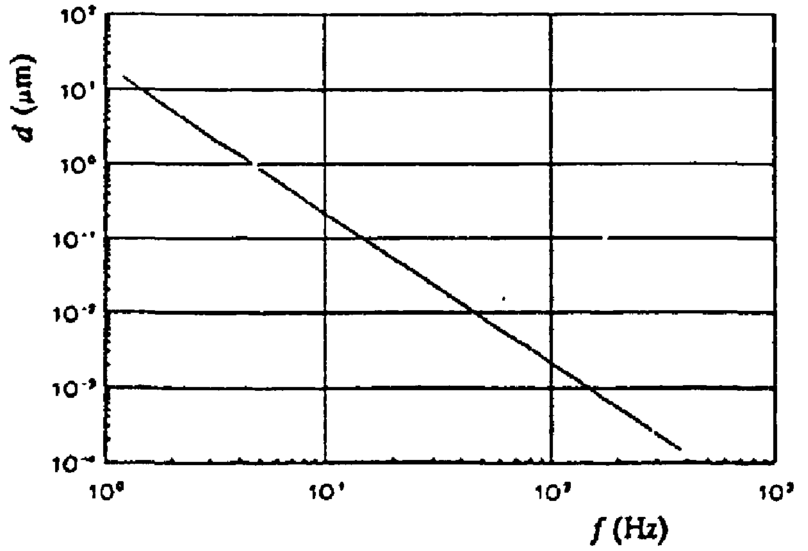


Figure 3. *Maximum displacement allowed (for $\phi < 10^{-4}$).*

described by $d = A \sin (2\pi x/\Lambda)$ (see Fig. 2). The maximum angle with the flat surface is given by

$$\phi = 2\pi A/\Lambda. \tag{3}$$

We require ϕ to be smaller than $\Delta\theta_{sw,\,max}$ (10^{-4} for the stringent and $5\cdot10^{-4}$ for the moderate case, respectively), yielding an expression for the maximum allowed A as a function of wavelength Λ, or -using the dispersion relation, Eq. (2)- as a function of frequency f, as shown in Fig. 3. Note, that the root mean square deviation of the angular offset, in an interval of one wavelength Λ, is $\sqrt{2}$ smaller than ϕ. For a given frequency ω the acceleration amplitude a is related to d as $a = - \omega^2 d$. The maximum displacement d is the amplitude A, yielding the maximum acceleration $a_{max} = A\ \omega^2 = \phi g$.

Requiring $\phi < 10^{-4}$ yields the maximum allowed acceleration, i.e. $a < 10^{-3}\ ms^{-2} = 0.1$ 'milli-g'. Note, that the requirement for a does not depend on f.

The frequency range, that may influence the reflection experiments, is at the low frequency part determined by the finite size of the sample. The length of the samples will in general be smaller than 10 cm, yielding a lower frequency limit of approximately 2 Hz (cf. Eq. (2) and Fig. 1.). The upper frequency limit is determined by the corresponding amplitudes. We will not consider amplitudes of the order of one molecule, i.e. a few tenth of a nm, corresponding with frequencies larger than approximately 200 Hz (see Fig. 3.). To give an impression how our specifications compare with other situations, we show in Fig. 4. both the maximum allowed accelerations for monumental buildings in Germany and the specifications for electron microscopy, as used by Philips.

3. MECHANICAL VIBRATIONS IN FLOOR OF REACTOR HALL

3.1. Site description

In fig. 5. the part of the reactor hall is displayed, where ROG is planned to be installed. The floor, of 25 m diameter, is constructed on concrete poles. The locations of the poles are indicated in the figure. The concrete floor is approximately 1.1 m thick.

3.2. Measurements

Vibration measurements were performed by TNO-bouw, Delft, the Netherlands [J. van Soest, "Trillingen in reactorhal van het Interuniversitair Reactor Instituut", TNO-rapport B-91-0244, (1991), ROG110/m]. Here we will summarise the method and results. Two types of sensors have been used. Three acceleration sensors (denoted a1, a2 and a3) and two displacement sensors (denoted v4 and v5). The sensors were attached to the floor at positions indicated in Fig. 5. All three directions x, y and z (see Fig. 5.) have been investigated. One long series of measurements has been performed on february 18th, 1991, from 4:30 a.m. untill 15:30 p.m., where each 3 minutes data were collected during a period of 3.5 s, yielding variance spectra, both for the acceleration and displacement, reliable in the frequency range from 1 to 150 Hz. To study the influence of sources of vibrations, commonly present during operation of ROG, part of the measuring time three of these sources were switched on, viz. the pumps used for forced cooling of the reactor, a chopper placed close to the sensors, and a vacuum pump. The cooling pump

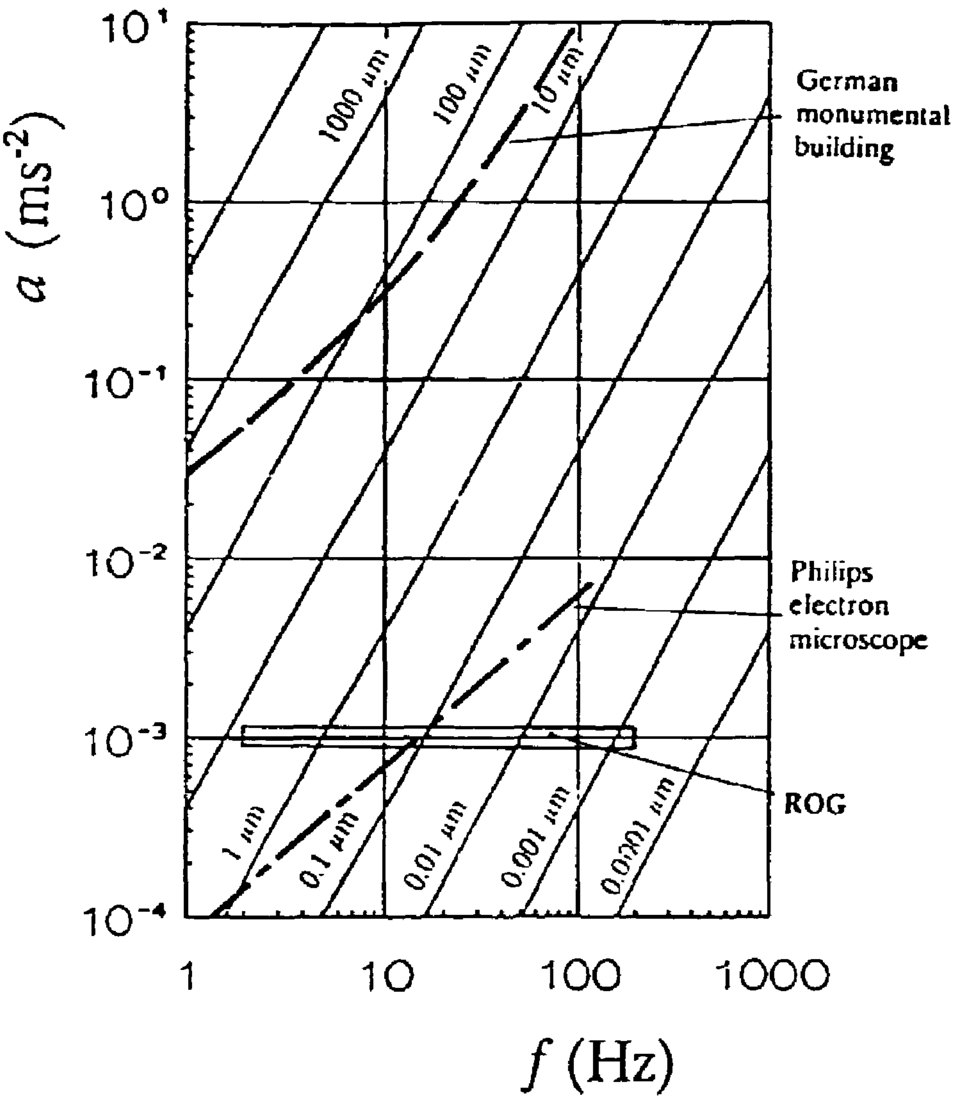


Figure 4. *Vibration specifications of ROG, Philips electron microscope and German monumental buildings.*

was on from 10:58 - 11:18, 11:38 - 11:44, and from 14:10 on. The chopper was started at 11:34 and the vacuum pump was started at 14:58. On february 19th, 1991, three short measurements were performed. During the first one, a fork lift truck was driven outside, close to the reactor hall. During the second one some persons walked around close to the sensors, and during the third one the crane in the reactor hall was operated.

3.3. Results

Typical results from the acceleration and the displacement measurements are shown in Figs. 6 and 7, respectively.

First we will discuss the results from the series of measurements d.d. february 18th, 1991. Since the displacements measured were extremely small (see Fig. 7.), we will only consider the results from the acceleration sensors. The background values for a were of the order of 10^{-5} ms^{-2}. For the frequencies 50, 100 and 120 Hz peaks are visible. In Figs. 8-10, the peak values as a function

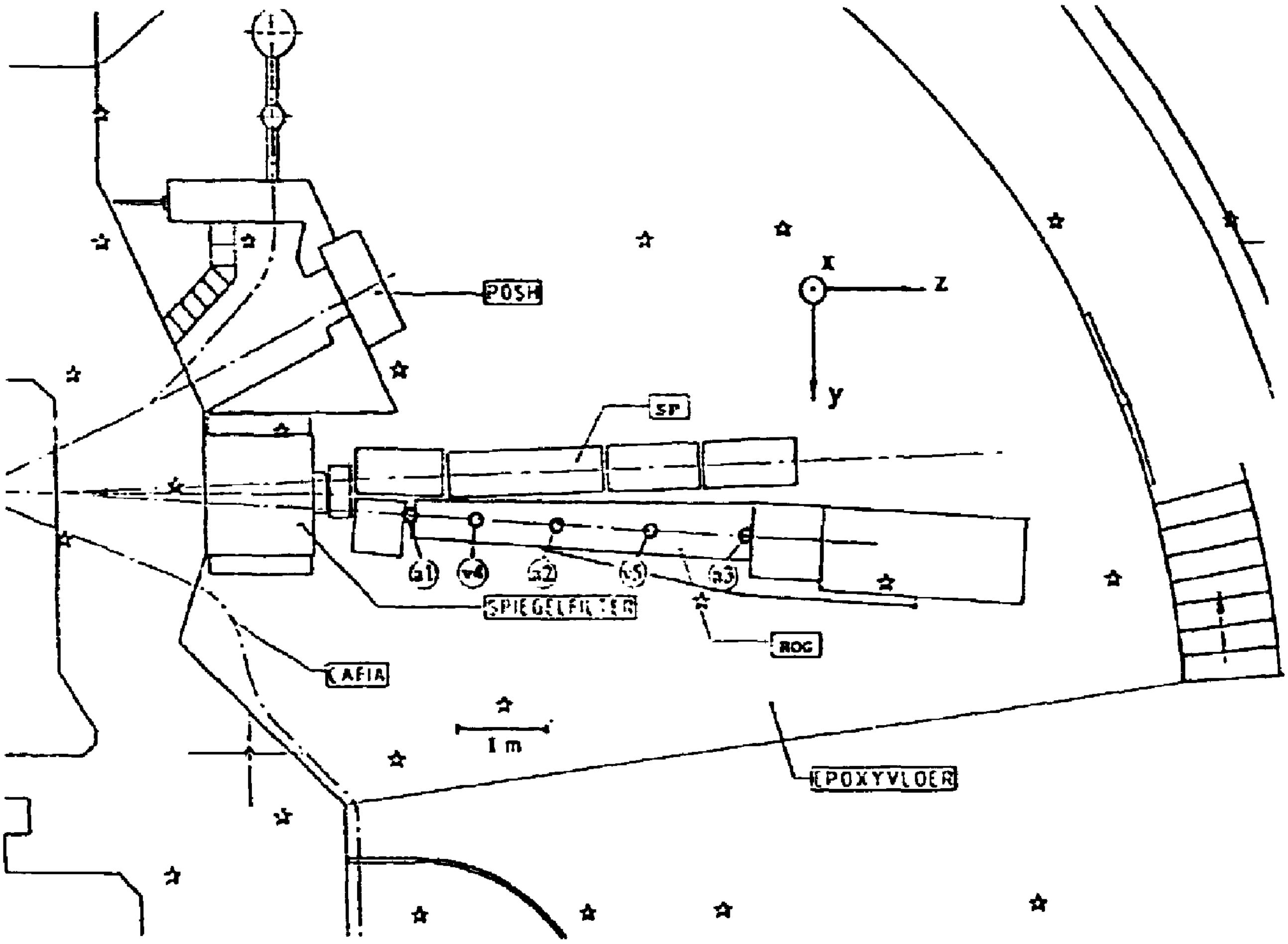


Figure 5. *Future plan of the IRI reactor hall. Sensors are indicated (see text). Stars: position of the concrete poles.*

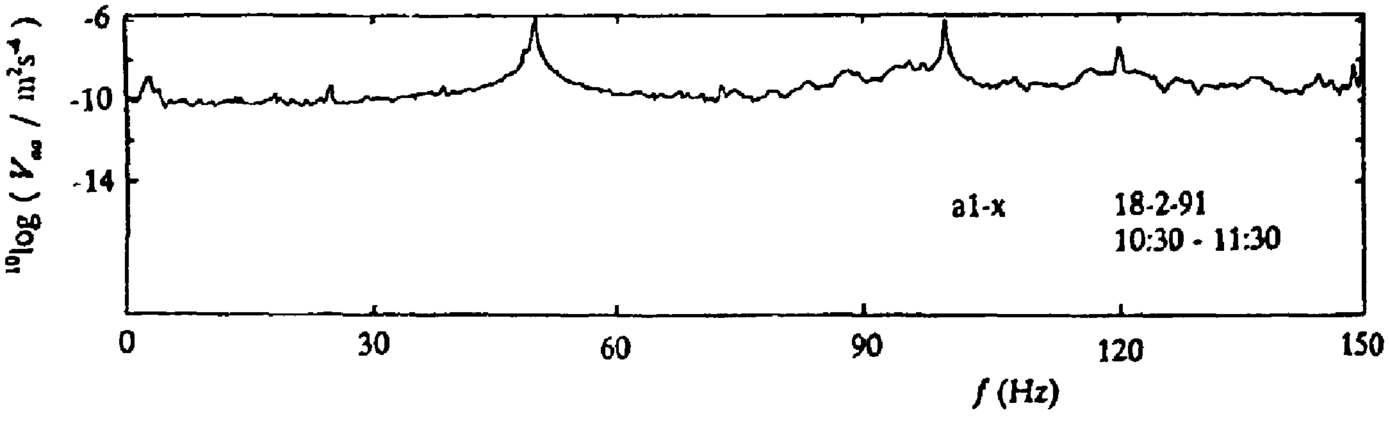


Figure 6. *Variance spectrum of the accelerations as a function of frequency.*

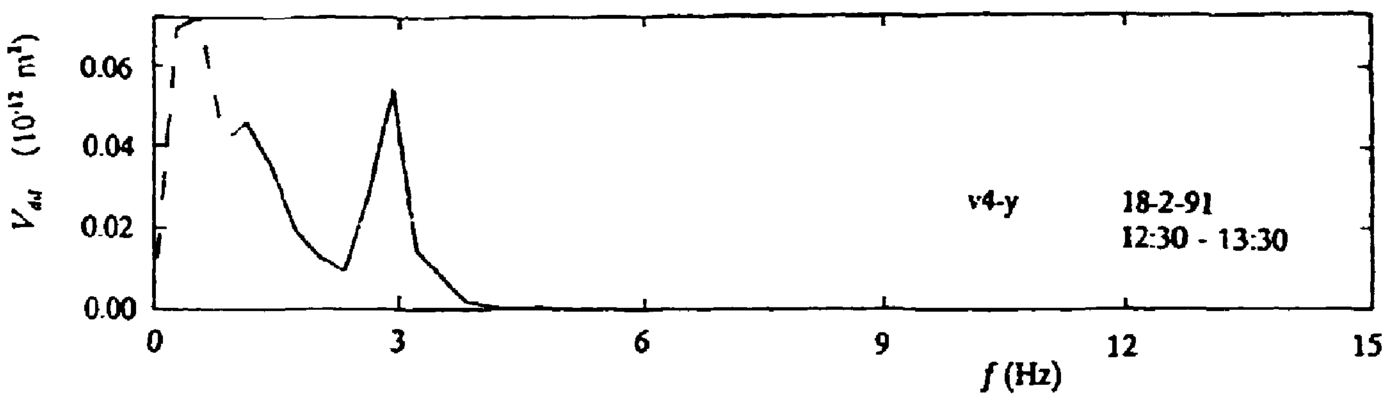


Figure 7. *Variance spectrum of the displacements as a function of frequency.*

of day time are shown for all three sensors in all three directions.

The results of the short measurements at february 19th, 1991, are summarised in Table I. Note that for these measurements, the displacements at the lower frequencies are clearly present.

TABLE I. *Peak values of the vibrations due to several types of disturbances.*

		acceleration		displacement	
		f (Hz)	*a* (ms^{-2})	*f* (Hz)	*d* (μm)
disturbance:					
fork lift truck		50/100	$\leq 2 \cdot 10^{-3}$	1 - 3 7	~ 0.2 0.3
walking		50/100	$< 10^{-3}$	~ 3	0.2
crane	start/rotate	50/100	$< 10^{-3}$	< 3	0.2
	bump/shock	50/100	$< 10^{-3}$	~ 5	0.4

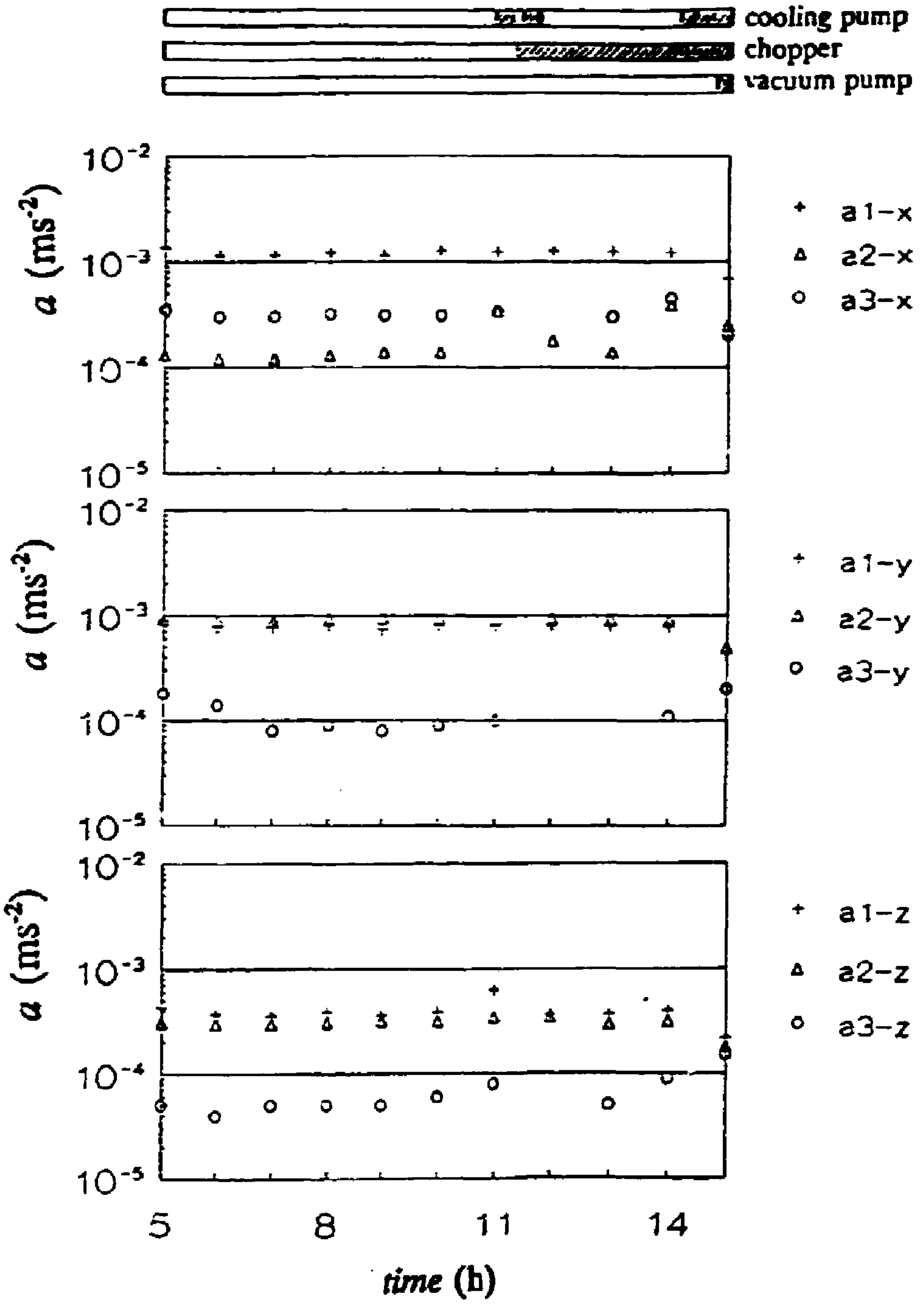


Figure 8. *Peak values of the accelaration amplitude a, at 50 Hz, as a function of day time on february 18th 1991.*

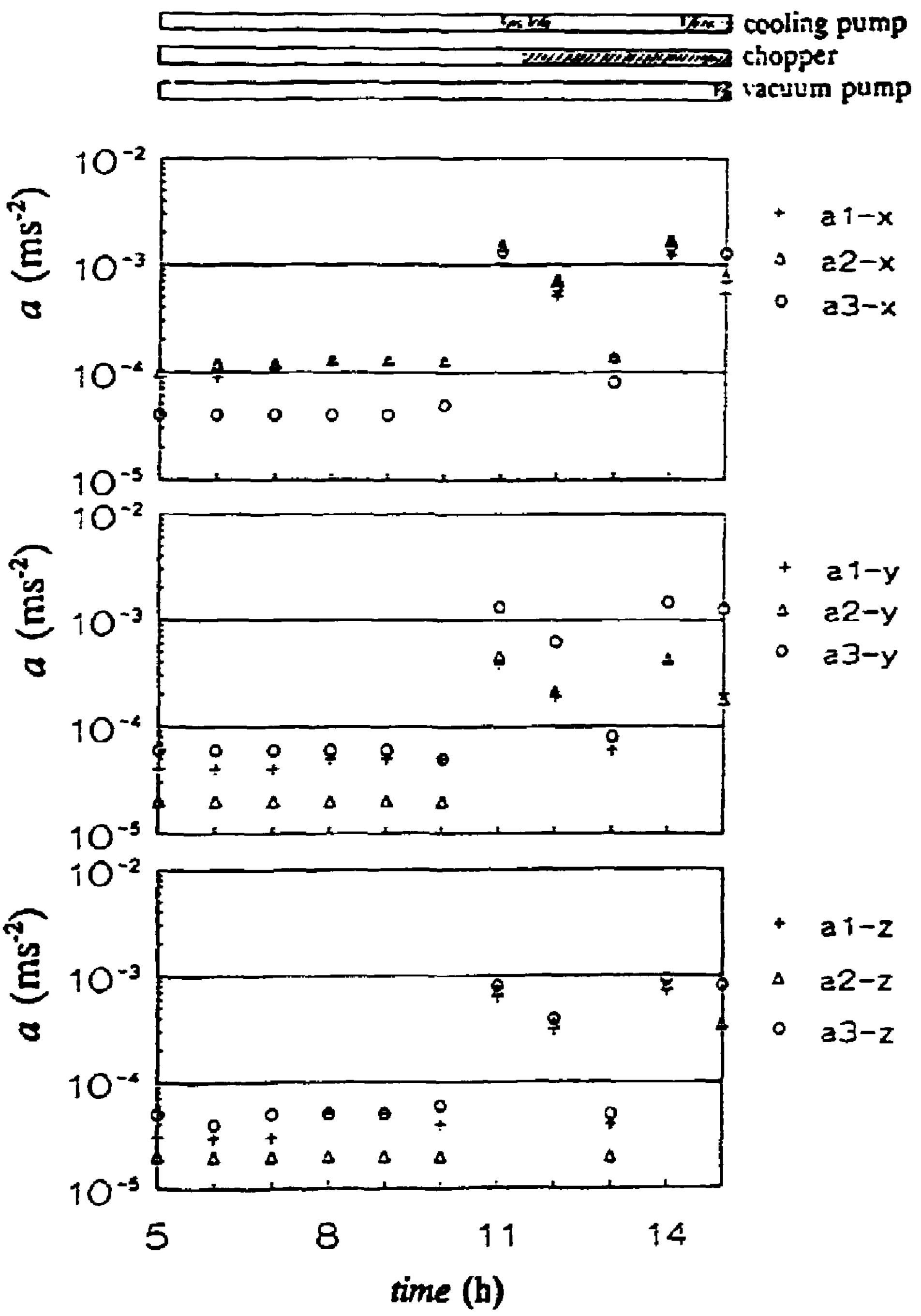


Figure 9. *Peak values of the accelaration amplitude a, at 100 Hz, as a function of day time on february 18th 1991.*

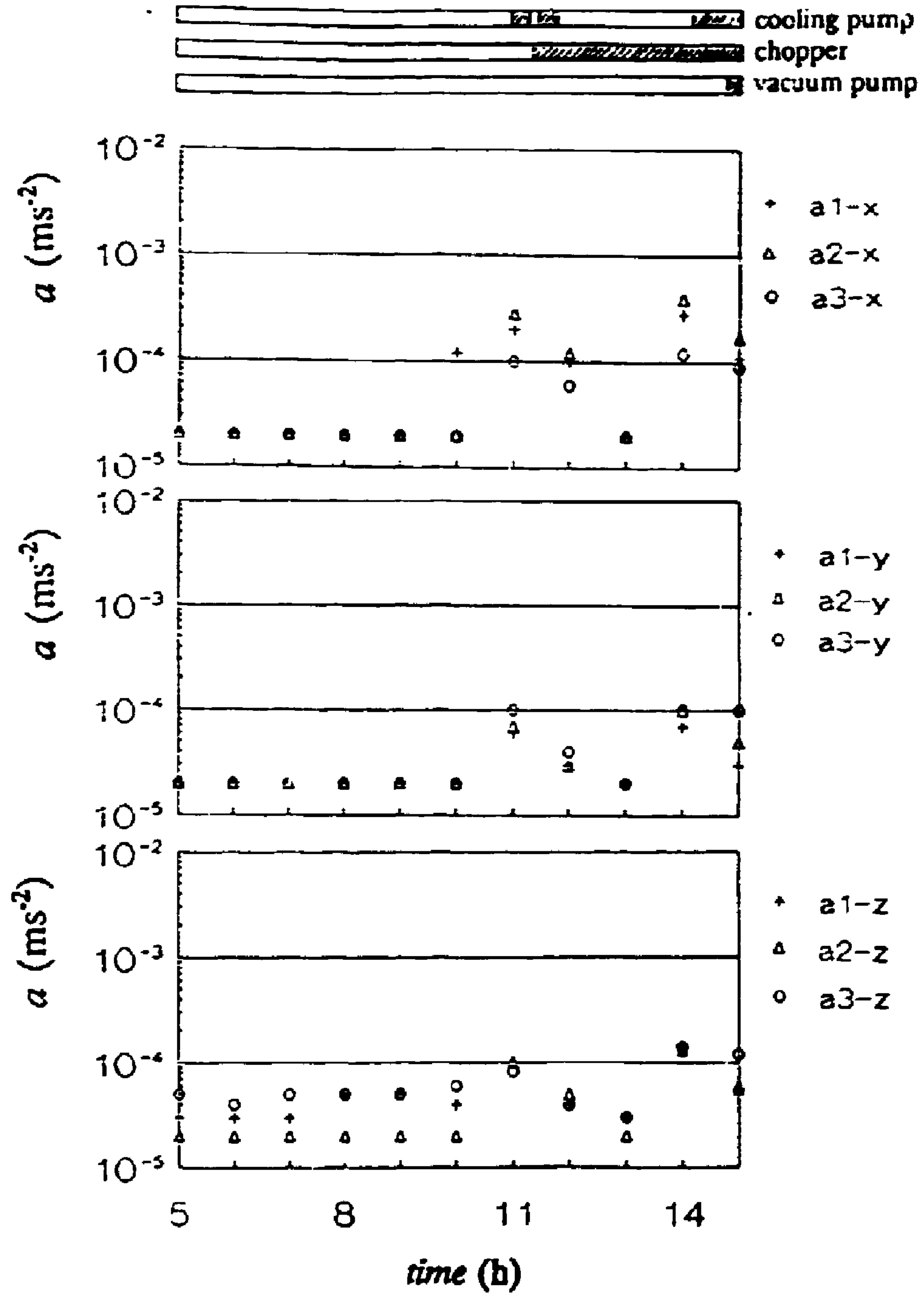


Figure 10. *Peak values of the accelaration amplitude a, at 120 Hz, as a function of day time on february 18th 1991.*

4. CONCLUSIONS

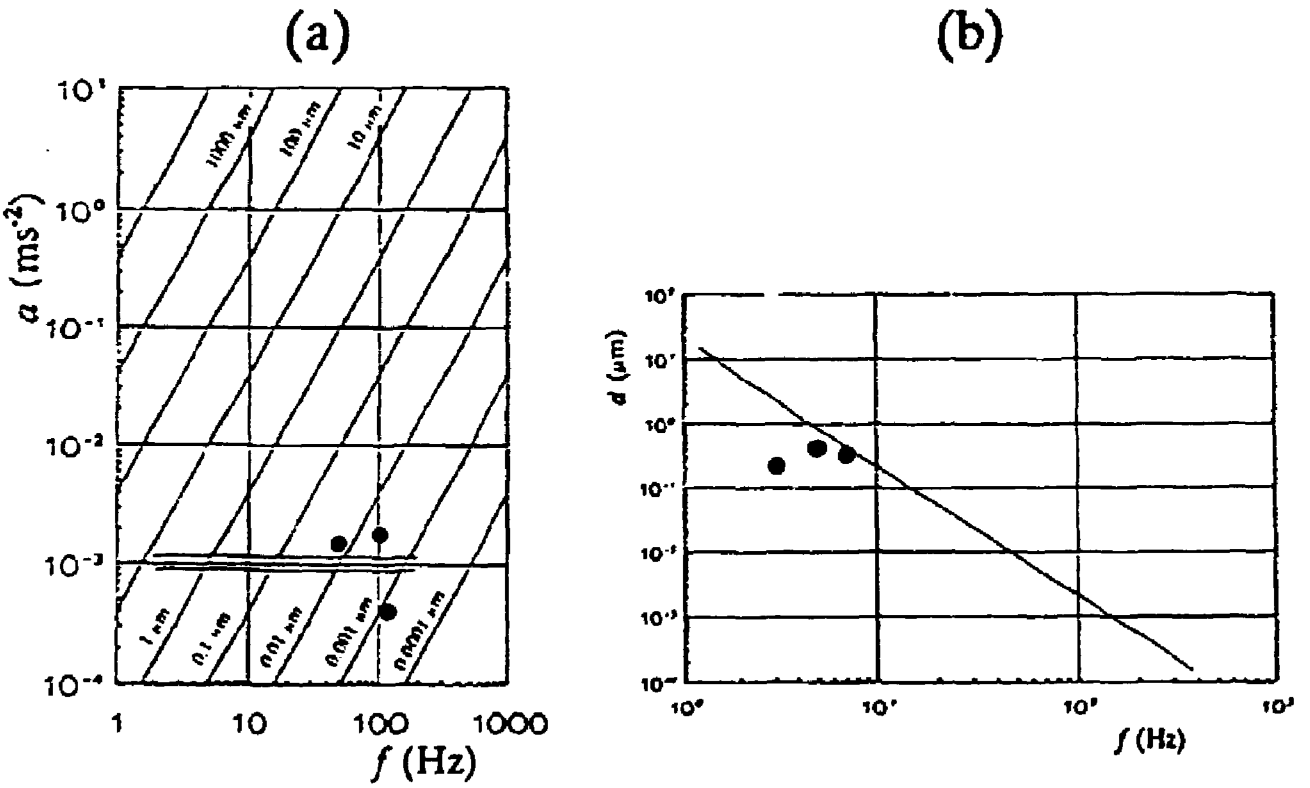
In general we conclude that the vibration level in the reactor floor is very low.

The results, displayed in Figs. 8-10, show that operating a chopper or a vacuum pump has no measurable effect on the acceleration amplitudes. Operating the cooling pump of the reactor, results in an enhancement of the acceleration amplitudes for the frequencies 100 and 120 Hz. The peak values are shown in Fig. 11(a). The maximum amplitudes measured are ~ $2 \cdot 10^{-3}$ ms^{-2}. Compared with the stringent (moderate) requirement of 10^{-3} ($5 \cdot 10^{-3}$) ms^{-2} (see Sec. 2.2), these are acceptable values.

As shown in Table I, the influence of driving a fork lift truck, of walking, and of operating the crane is measurable in the low-frequency displacements. However, these displacement amplitudes are well below the required values, as shown in Fig. 11(b).

In the mechanical construction of ROG, eigenfrequencies in the range 1 - 7 Hz, and around the frequencies 50, 100 and 120 Hz, should be avoided.

If, after all these precautions, vibrations at the sample position still result in unwanted resolution effects, the use of a dynamic vibration isolation system (manufacturer JRS, type MOD2) at the sample position is foreseen. The transmissibility for vibrations of this system decreases from 1 at 1 Hz, to 0.2 at 3 Hz, 0.05 at 7 Hz, and 0.02 between 10 and 100 Hz.



Figuur 11. Acceleration (a) and displacement (b) amplitudes as a function of frequency.
(a) Bar: ROG requirements for maximum acceleration (Sec. 2.2, Fig. 3); dots: peak values measured at the reactor floor (Figs. 8-10).
(b) Continuous line: ROG requirements for maximum displacements (Sec. 2.2, Fig. 4); dots: peak values measured at the reactor floor (Table I).