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RECORDER ROTATIONAL GROUND VIBRATION

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ABSTRACT
The rotation components of seismic ground motion can be radiated from the source, or can be generated when seismic waves spread through anisotropic (micromorphic) rock massif or rise as the response of building structures on dilatational excitation. In order to experimental study these questions, new sensors of rotational ground motion were constructed. They use cooling air blowers from standard PC. This easy construction seems to be satisfactory for monitoring strong ground motion forced by near earthquakes, rockbursts and production blasting. In principle this sensor is as an elementary mechanic oscillator with constant natural frequency f_S and small damping constant D. The value of maximum amplitude of oscillatory response to seismic ground motion is digitized and stored on hard disc of PC in a triggered regime. The time of events is taken from PC clock synchronised by the time signal of DCF 77 station.

KEYWORDS: rotation component, ground motion, seismic, recorder, rockburst, transfer function, amplifier, electronic, filter, selective, response, natural frequency, AD converter, cooling blower , damping, quality factor

1. INTRODUCTION

The rotation component of strong ground motion can represent a non-negligible contribution to the whole earthquake hazard to building structures in near zones. The excitation of rotation vibration depends on the structure of subsoil, on the dynamic response of building structures and on build-in components, as well as. This holds especially for building constructions with prevailing linear shape, such as pipelines and rail rapid transit lines, and for objects with great seismic risk (e.g. nuclear power facilities), great seismic vulnerability (e.g. astronomical instruments) and for buildings with enormous historic costs.

The sensors of rotational vibration motion are based on the principle of flywheel, which must be balanced exceedingly accurate because of the ratio of rotation-to-translation sensitivities must be very high.

A transportable sensor for field measurements was constructed by using a rotation shaft, hinged in bearings. An electro-dynamic converter of Deprez type, taken from a pen-writing oscillograph, was described in (Buben and Brož, 2002). This ongoing paper deals with a rotation oscillatory system and electromagnetic converter, both construed from cooling air blowers, which are commonly used in all PC.

2. SENSOR SR4

Prototype is made by slightly reconstruction air vessel propeller, mark SUNON 12V 2.8 W, KDE 1029 PTS1 (external dimensions 120mm x120mm x35mm). The support of rotation shaft is made of very precise ball bearings (external diameter 8mm, internal diameter 2mm and height 2mm). The restoring momentum of the screw is produced by magnetic attraction force between a magnetic ring and the electromagnetic armature of the propeller. The permanent magnetic ring is fixed to the rotation shaft and the armature is fixed to the frame.

The natural vibration frequency $f_s = 4\ Hz$ of this system is convening for picking the seismic vibrations. It is known that the design spectra for translational ground motion reach maximum values for frequencies about 4 Hz. Therefore no additional elastic and damping elements are used in this test model. Mechanical reconstruction blower consists only in switchover the terminals of electromagnet coils, connected in series to output clips. Their electric resistance is R_S = 82 Ohm and inductivity L_S = 0.15 H.

The oscillogram of output voltage on induction coil in the course of its free oscillation is shown in Fig.1. The envelope curve *Y(t)* is near-to exponential. It means that the dry friction in bearings is sufficiently small. The damping constant D is calculated from the relation $Y(t) = \exp(-D.n.t)$, where n is the count of periods and t is the current time.

Electro-dynamic constant B was calculated from amplitudes of angular deflection of the system measured by means of a laser light emitting diode with appropriate optics, a reflecting mirror and a screen with scale in distance A=1305 mm. Stationary oscillation of system at its resonant frequency F_S was excited by external electromagnet driven by a generator of continuous wave and an ferrous arm foxed to the vessel.

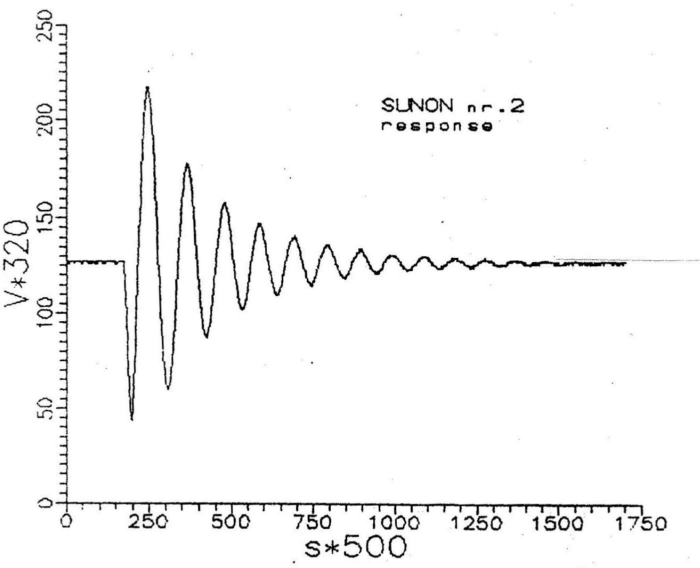

Fig. 1 Free oscillatory response of the sensor

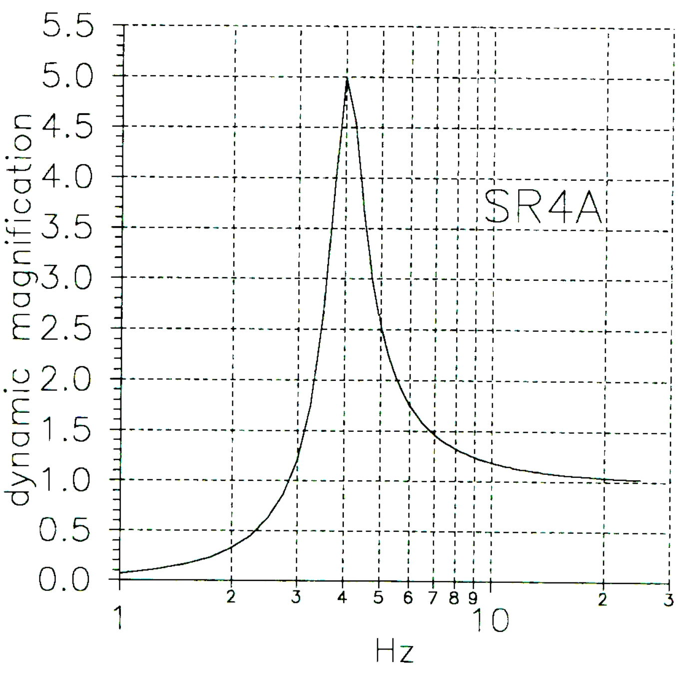

Fig. 2 Dynamic magnification of senor

The oscillation amplitudes „S“ = *40 mm* were measured at angular amplitude of system $\varphi_s = S/A = 0.03065^0$, *e.g. 0.534* miliradian. For natural frequency 4Hz is corresponding angular frequency $\omega_S = 25\ s^{-1}$. The voltage on the induction coil $e_c = 8\ mV$ was measured by a storage oscilloscope. The value of electro-dynamic constant B satisfies the relation

$e_c = B * \varphi_s * \omega_S = 8\ mV.$

Substituting the measured values, one obtain

$B = e_c / (\varphi*\omega_S) = 0.008\ [V] / (0.000534\ [rad] * 25\ [1/s]) = 0.6\ [V*s/rad].$

The output voltage *E* on the coil, moving with angular amplitude φ and angular frequency $\omega = 2\pi * f$ obeys the same relation, i.e.

$E = B* \varphi *\omega.$

The response of linear mechanic harmonic oscillator to sinusoidal ground vibration is described by the well-known function called dynamic magnification $U = Y/S$, where *Y* is amplitude of forced mechanical vibration:

$U = u^2 / [(1 - u^2)^2 + (2*D*u)^2]^{1/2},$

where $u = f/f_S$. The course of dynamic magnification (SR4A) is shown in Fig. 2.

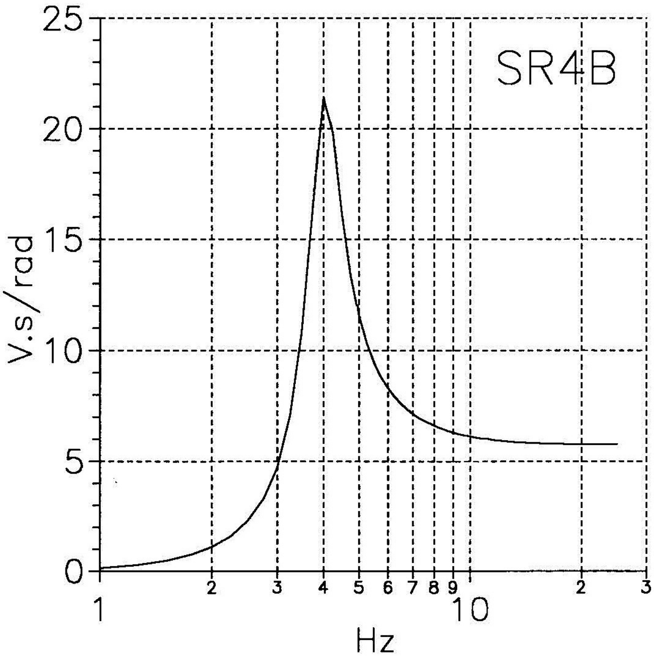

Fig. 3 Voltage sensitivity of sensor

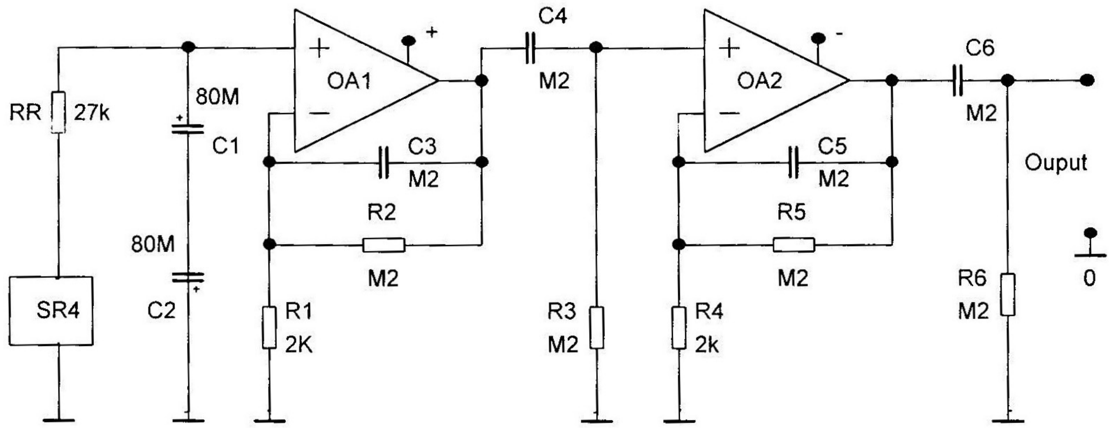

Fig. 4 Wiring diagram of the amplifier

When our sensor SR4 with its electromagnetic transducer is excited by ground motion vibration with angular rate rad/s then it generates the output voltage $V = U^*E = U^* B^* \varphi * \omega$. Its voltage response, graph SR4B, is shown in Fig.3. This figure indicates, that the voltage sensitivity, expressed in [Volt*s/rad], asymptotically approaches a constant value for frequencies $F >> 4$Hz. Local maximum, caused by mechanical resonance, appear at natural frequency f_S of system.

3. ELECTRONIC AMPLIFIER

It shall be kept in mind that we are going to measure only the response of this elementary oscillator at its natural frequency 4Hz. In this way, we obtain only one point of the whole response curve of a set of elementary oscillators. Fortunately, for translational seismic ground motion, the response reaches its maximum value just at the frequency 4 Hz. This empirical fact is discussed elsewhere, e.g., (Buben and Rudajev, 2004). Therefore it can be supposed, that the rotation vibration response will reach its maximum at about 4 Hz, too. From this reason the air-blower with suitable frequency was chosen. For the above supposition, the desired shape of amplitude – frequency characteristic of the sensor shall be sharply selective with maximum at 4 Hz, and the resonance curve shall be slope down symmetrically for lower as well for higher frequencies. Characteristics shown Fig.3 can be converted to the desired shape by means of a frequency-dependent amplifier.

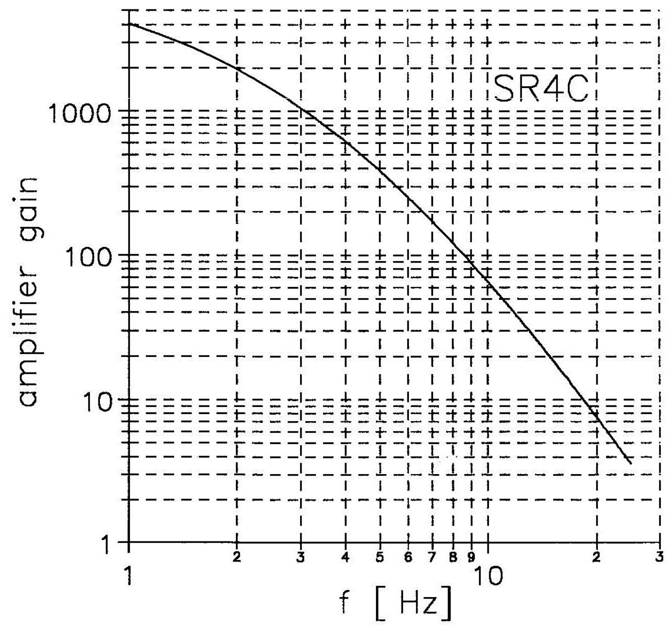

Fig. 5 Amplitude frequency characteristics of amplifier

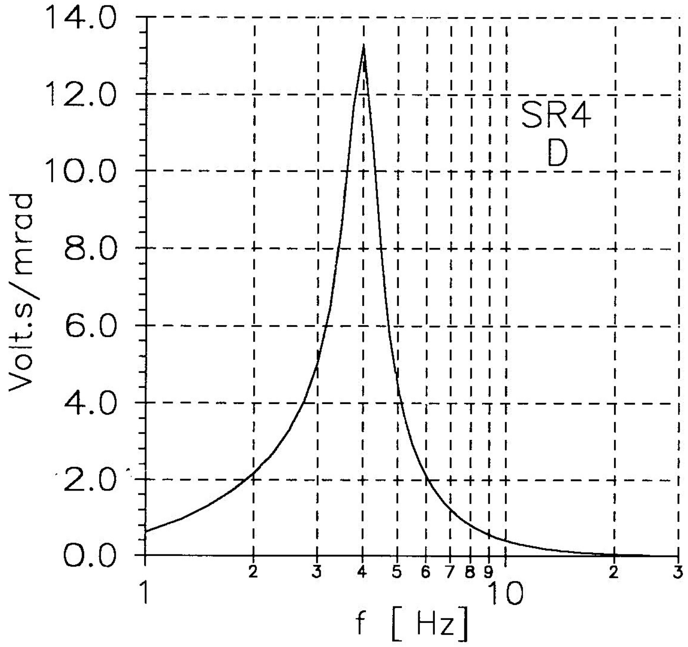

Fig. 6 Amplitude frequency characteristic of recorder

The wiring diagram of such an amplifier is shown in Fig.4. Its amplitude-frequency characteristic (SR4C) is illustrated in Fig. 5. The scaling factor (not frequency-dependent) of this amplifier is governed by the values of resistors R1 and/or R4 but the increase of this scaling factor is limited by electric noise of operation amplifiers. Level of this noise (at 4 Hz) can be assessed about 1 μV. For actual values R1 = R4 = 2 kΩ, the noise voltage on the amplifier output reaches about 0.6 mV. Capacitors $C_1 = C_2 = 80$ μF serve to decrease the level of electric noise. It was experimentally proven that they practically do not affect neither the natural frequency *Fs* nor damping *D* of the sensor.

The amplitude-frequency characteristics SR4D of the whole pick-up (sensor with amplifier) is shown in Fig. 6. This characteristic was calculated from following relations:

Amplitude – frequency characteristic Z of integrators

$Z = [(R/r) / (1 + R. C. \omega)]^2$

where C = C3 = C5, R = R2 = R5 and r = R1 = R4, see Fig.3.

Amplitude – frequency characteristic X of coupling RC network

$X = [1 / (1 + S . G . \omega)]^2$

where S = R3 = R6, G = C4 = C6, see Fig.3.

Amplitude – frequency characteristic SR4D of the whole sensor

SR4D = Z . X . E

The sensitivity reaches its maximum value 13.3 Volt per milirad/s at frequency 4 Hz.

The quality factor Q of sensor can be determined from of the shape of resonance curve SR4D. The halve values of maximum sensitivity 13.3 corresponds to frequencies f_1 = 3.3 Hz and f_2 = 4.6 Hz. The so defined frequency band is Df = (f2 – f1) / 2 = 0.65 Hz and the quality factor s Q = fs / Df = 6.2.

4. THE A/D CONVERTER

The signal from amplifier output is fed to the 12-bit A/D converter (mark AD12, product of firma Janas Card, Praha). Full scale input voltage of this converter is ±5 Volt and the corresponding output code N is ± 4096.

For ground motion rate 10^{-6} rad/s , i.e., the AD input voltage 13.3 mV, the AD output code is N = 4096 * 0.0133 / 5 =10.9 ~ 10. If we accept, that the amplitude of minimum measurable wave train can be about N = 100 bits, then it follows that described sensor SR4 can be used for monitoring the rotation vibration with amplitude at least 10^{-5} rad/s.

If the amplified electric noise level of pickup and operational amplifier reaches the voltage 0.63 mV than the corresponding AD output code is N_n = 4096 * 0.00063 / 5 < 1. This value is 100 times smaller that the amplitude of minimum measurable wave amplitude.

5. TEST RECORDING AND PERSPECTIVE APPLICATION

The upcoming question is the rotation response of building structures being excited by translation seismic ground motion. Since September 2003, the prototype of rotation sensor SR4 was placed on the widow embrasure in the 2nd floor of the IRSM building in Praha-Libeň. The rotation axis was oriented in vertical direction. Some events per day are recorded, mainly in periods of most live traffic in the nearby 40m distance from the building.

A mobile field station consisting of the SR4 rotation seismometer and digital storage recorder with notebook mark DELL Latitude XPi is used for recording in the vicinity of sources technical seismicity.

Another live question is the ratio of translation-to-rotational ground motion in the vicinity of production blasts foci In the open pit coal mine Tušimice in western Bohemia.

In order to construct sensors with tuneable selectivity, two sensors SR were mechanically coupled together. The filtered output voltage of one sensor is fed to the coil of the second one. This feedback can be applied to modification the amplitude-frequency characteristic of sensors and construct the apparatus for recording the response on a greater number of frequencies.

ACKNOWLEDGMENT

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