Title	Estimating seismometer parameters by step function (STEP)
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1 Aim

To determine the response of a seismometer system in the time domain to a *STEP function* input. Applying a step impulse to a seismometer allows to derive the main seismometer parameters by analysing the generated time series. In the absence of expensive calibration equipment (e.g., shake table) or in the case of sealed seismometers this simple method is very suitable and can also be used under field conditions.

2 Procedures and relationships

2.1 Applying STEPs to the seismometer

Applying steps is the oldest calibration method in seismology. Teupser (1962) describes three main types:

a) pulling a thin block (thickness max. 0.01 mm) off the seismometer bottom;
b) applying a heavy weight upon the seismometer platform;
c) applying a constant current to the coil of an electrodynamical system (if available; for driving current see EX 5.3: Seismometer calibration by harmonic drive).

Because a) is the roughest method one should use it for field or for portable seismometers only and never for sensitive station sensors. In case a) and b) the seismometer mass will return to the former position after deflection, in case c) the seismometer mass will move to an offset position which will depend on the applied current. To ensure linearity the mass deflection - or the seismometer displacement - should not exceed several 100 micrometers.

2.2 Evaluating STEP-transition time series

2.2.1 All types of seismometers ($D_S < 0.5$)

Figure 1 shows the time series of a low-damped seismometer ($D_S = 0.1$). The time section A represents the time from the moment of step input up to the transition to a real harmonic movement of the mass. The moment of step causes odd signals. Mechanical application of a step impulse generates additional vibrations because of hitting effects. An electrical step can induce an electrical pulse if the calibration coil and the signal coil are mounted to the same core (the so-called transformer effect). Therefore the analysis of the generated time series should start only beyond section A with:

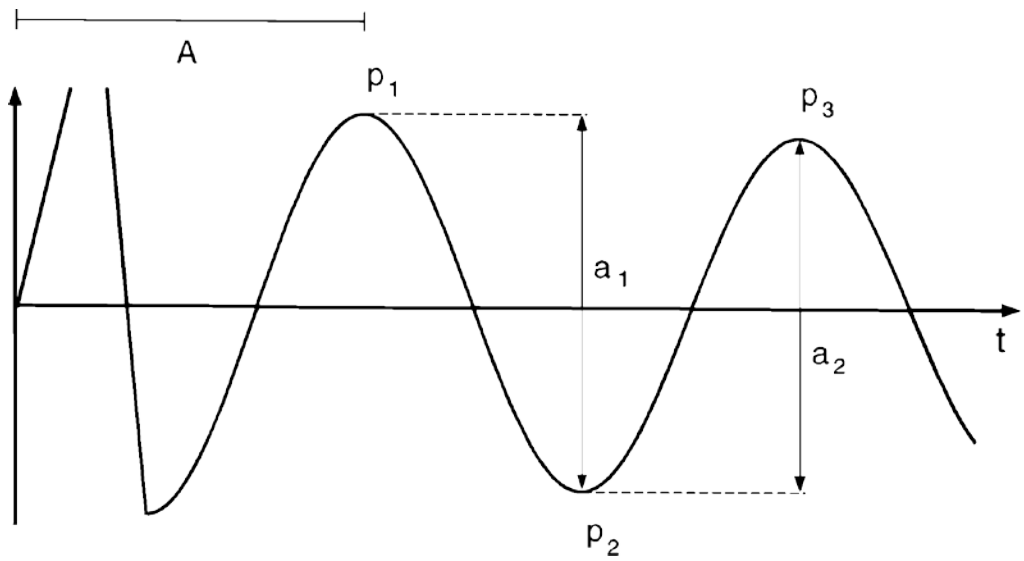

Figure 1 Response of a low-damped seismometer to a step pulse.

First step: Measuring of the period and damping of the time series.

The period T should be measured by averaging over as many cycles as possible (10 or more) to get an accuracy better than 99%.

Note! The measured period is larger than the natural period because of the seismometer damping.

The damping D is calculated from the equation

$$D = \frac{1}{\sqrt{\left(\frac{(N-1)\pi}{\ln(a_1/a_N)}\right)^2 + 1}} \tag{1}$$

with a_1 as the double amplitude between the first two oscillation peaks (p_1 and p_2) and a_N as the double amplitude between the peaks (p_N and p_{N+1}). N should be selected so as to get an $a_N \approx 0.2 \ldots 0.4\ a_1$.

Second step: Estimation of the natural period T_S of the seismometer.

If possible switch off all external attenuators (e.g., resistors) to decrease the measuring error. For example: with a damping D = 0.2 the measured period is $T = 1.02\ T_S$.
The natural period of the seismometer is

$$T_S = T\sqrt{1-D^2}\ . \tag{2}$$

2.2.2 Electro-dynamical system (moving coil)

The electrodynamical constant (or generator constant) G_S of a moving coil system can also be estimated by step transition via its relation to damping D. The complete seismometer damping D_S is

$$D_S = D_{S0} + D_G \qquad (3)$$

with D_{S0} as the natural damping of the seismometer (mostly mechanical effects), and with D_G as the moving coil damping. The latter is caused by an external resistor R_a shorting the coil (electromagnetic force), i.e.:

$$D_G = \frac{G_S{}^2 T_S}{4\pi m_S (R_a + R_S)} \,. \qquad (4)$$

Except for R_a and T_S all other parameters in Equation (4) are documented by the manufacturer and will not change over time. While for pendulum seismometers usually the parameters

- K_S [*kg.m²*] inertial moment
- l_0 [*m*] reduced pendulum length

are given instead of m_s one gets for geophone systems

- m_S [*kg*] = $K_S\, l_0^{-2}$ seismic mass and
- R_S [*Ohms*] coil resistance.

Note! When measuring coil resistance don't forget to lock the seismometer.

The evaluation again starts as above with: measuring of the period and damping of the time series as the first step and the estimation of the seismometer's natural period T_S as the second step.

This is followed by:

Third step: Estimation of the seismometer's natural damping D_{S0}.

The external damping resistor must be removed (open circuit). Then we get, similarly to (1),

$$D_{S0} = \frac{1}{\sqrt{\left(\frac{(N-1)\pi}{\ln(a_1 / a_N)}\right)^2 + 1}} \,. \qquad (5)$$

Fourth step: External damping.

The external resistor must be set to a value that causes a damping down to 20 - 50% per period. Then we measure the neighbouring amplitudes a_1 (between p_1 and p_2) and a_2 (between p_2 and p_3; p_2 is used twice to reduce measuring error) and get

$$G_S \quad [Vs/m] \quad = \quad \sqrt{(D_S - D_{S0})\frac{4\pi}{T_S} m_S (R_a + R_S)}\ .$$

(6)

This constant can also be used when calibrating a system by harmonic drive.

Note! For pendulum seismometers there are different notations for this constant:

1)	force/current	[N/A]	= [Vs/m]	and
2)	torque/current	[Nm/A]	= [Vs]	

They are related via the reduced pendulum length l_0 as follows:

$$G_{S_{1)}}[V_S] = G_{S_{2)}}[V_S\ /\ m] \cdot l_0[m]. \qquad (7)$$

3 Data: Application to a specific seismometer

Below a typical seismometer parameter list is given.

Mechanical constants:		
Natural period	T_S	. . . . . . s
Open damping (Attenuation)	D_{S0}	. . . . . .
Reduced pendulum length	l_0	0.0785 m
Inertial moment	K_S	0.0201 kg m²
Seismic mass	m_S	. . . . . . kg
Transducer constants 1 (signal coil):		
Coil resistance	R_{S1}	6030 Ω
Electrodynamical constant	G_{S1}	. . . . . . V_S/m
Transducer constants 2 (calibration coil):		
Coil resistance	R_{S2}	835 Ω
Electrodynamical constant	G_{S2}	. . . . . . V_S/m

4 Tasks

Task 1:
Mark those seismometer parameters which are absolutely necessary for calculating the seismometer response curve (BODE-diagram).

Task 2:
Complete the list above by analysing the related time series plots in Figure 2a - c.

Task 3:
Calculate the current I_C through the calibration coil which is necessary to deflect the seismometer mass by 1 µm at a frequency f = 1 Hz (see EX 5.3: Seismometer calibration by harmonic drive).

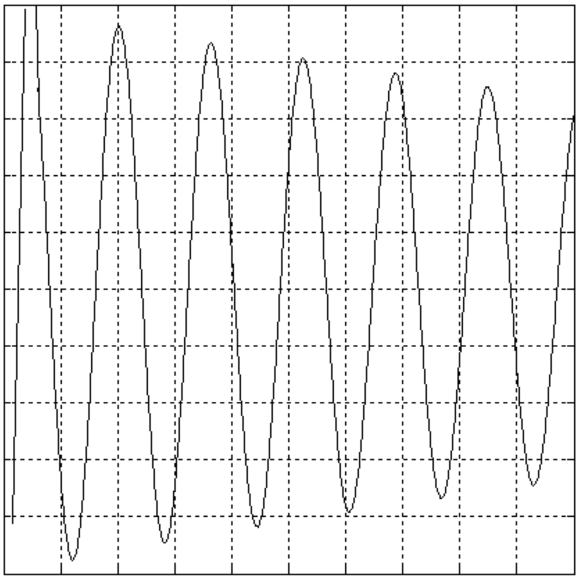

Figure 2a Seismometer step response: open circuit.

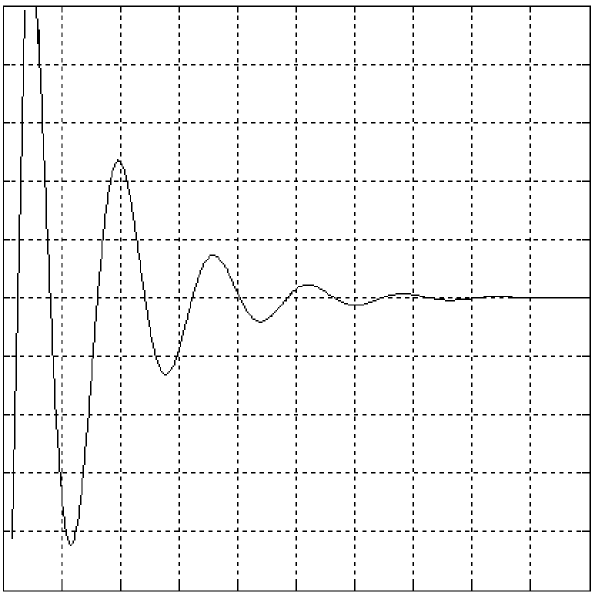

Figure 2b Seismometer step response: signal coil with external resistor R_a = 67 kOhm.

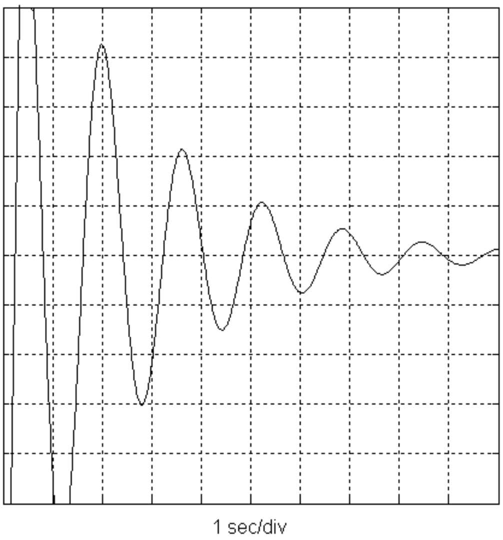

Figure 2c Seismometer step response: calibration coil with external resistor R_a = 1 kOhm.

5 Solutions

Task 1:
Seismometer parameters absolutely necessary for calculating the seismometer response curve are marked by an asterisk (*) in the listing below (see Task 2). Additionally required are the *seismometer damping*, consisting of the *open damping* plus the *external* (here: *electrodynamical) damping.*

Task 2:
Completed list of seismometer parameter:

Mechanical constant:

Natural Period	T_{S0}	=	1.617 s	(*)
Open damping (attenuation)	D_{S0}	=	0.0102	
Reduced Pendulum Length	l_0	=	0.0785 m	
Inertial Moment	K_S	=	0.0201 kg m²	
Seismic Mass	m_S	=	3.262 kg	

Transducer constants 1 (signal coil):

Coil Resistance	R_{S1}	=	6030 Ω	
Electrodynamical Constant	G_{S1}	=	571.1 Vs/m	(*)

Transducer constants 2 (calibration coil):

Coil Resistance	R_{S2}	=	835 Ω
Electrodynamical Constant	G_{S2}	=	67.97 Vs/m

Task 3:

In order to deflect the seismometer mass for 1 µm, a current of I_C = 0.12 mA has to be driven through the calibration coil.

References

Teupser, Ch. (1962). Die Eichung und Prüfung von elektromagnetischen Seismographen, *Freiberger Forschungshefte C130*, 103 pp.