DETERMINATION OF SEISMOGRAPH SYSTEM TRANSFER FUNCTIONS
BY INVERSION OF TRANSIENT AND STEADY-STATE CALIBRATION
RESPONSES

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Summary: The methods and software tools for the identification of the low-frequency portion
of seismograph system transfer functions from transient (Dirac or step-impulse) calibration
responses and of the high-frequency portion from steady-state (sinusoidal) calibration data are
described. The presented procedures allow fast in-site determination of the overall Laplace transfer
function of the analog stages of arbitrary seismograph systems. The developed identification
software, which may also be employed for determining transfer functions in PAZ (poles and zeros)
format from steady-state calibration data given graphically or in the form of FAP (frequency-
amplitude-phase) triplets, has been made publicly available on the INTERNET. The paper is
expected to prove useful especially for seismologists faced with the problem of specifying reliable
calibration headers for digital upgrades of standard-class analog seismographs, for non-standard
feedback-controlled seismograph systems, or for seismometric channels comprising inverse or
simulation filters.

Keywords: seismograph systems, calibration responses, least-squares inversion, transfer
function

1. INTRODUCTION

The exact knowledge of the transfer functions of employed seismograph systems is the pre-
requisite for any advanced processing and interpretation of digital (or digitized analog)
seismograms. If the transfer function of the complete system including additional (anti-aliasing,
offset-removing, noise-suppressing, etc.) filters and the scale factor has not been unambiguously
specified by the manufacturer, and/or if the long-term stability of the system transfer properties are
not guaranteed, then the transfer function must be determined and regularly checked by means of
some appropriate calibration method. The basic principles and features of methods developed so far
for the in-site calibration of seismograph systems of different categories are summarized in Table 1.

The complexity of the cascade of analog stages of modern digital seismograph systems -
especially of those comprising inverse or simulation filters (Wielandt, 1970; Teupser et al., 1977),
feedback-controlled broadband seismometers (Plešinger and Hordlek, 1976; Usher, Burch and
Guralp, 1979; Wielandt and Steim, 1986) or molecular electronic sensors (Cobern and Abramovich,
1997) - makes reliable determination or verification of the overall analog transfer function by either
the parametric, the steady-state, or the transient method alone impracticable, or even impossible.
A comparative study performed by Wielandt (1986a) has shown that the most appropriate for the
calibration of electronic force-balance seismometers for digital, broadband, large dynamic range
systems is the random signal method. However, this method requires the generation of special
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calibration signals, simultaneous high-resolution digital recording of both the input and output signals of the tested system, and processing of the data by a suitable identification program. These tools may be available at advanced observatories, but hardly at single or "exotic" stations. Since the data from the latter stations are equally important for regional and global seismological studies as those from prominent observatories or arrays, they should also be equally reliable.

Table 1. Principles and basic features of seismograph system calibration methods.

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<thead>
<tr>
<th>Method</th>
<th>Principle</th>
<th>Features</th>
<th>References</th>
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<tr>
<td>Parametric</td>
<td>Direct measurement of the system parameters necessary for determining the coefficients of the analytical transfer function.</td>
<td>Cumbersome. Does not reveal possible anomalies of the actual response (e.g. parasite resonances). Applicable to a limited class of instruments only (e.g. standard electromagnetic seismographs).</td>
<td>Willmore and Kárník, 1970</td>
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<td>Steady-state</td>
<td>Measurement of the steady-state amplitude gain and/or phase delay of the system with sinusoidal signals at frequencies across the system’s passband. Determination of transfer function approximating the measured frequency response.</td>
<td>Insensitive to non-linearities and noise. Time-consuming, especially in case of long-period systems Enables accurate approximation of even the high-frequency part of the system transfer function.</td>
<td>Willmore and Kárník, 1970</td>
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<tr>
<td>Transient</td>
<td>Measurement of system responses to Dirac or step impulses. Enhancement of signal-to-noise ratio by summing up responses from repeated measurements. Determination of transfer function approximating the measured time response.</td>
<td>Sensitive to non-linearities and noise. Fast and simple. Enables accurate calibration of the low-frequency part of the system transfer function only.</td>
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