

**STATE OF CALIFORNIA
SYSTEM REQUIREMENTS
CENTRAL RECORDING MULTICHANNEL ACCELEROGRAPH RECORDER SYSTEM**

REVISION DATE: 10/04/2007

1 SCOPE

This document establishes the requirements and specifications for a Central Recording Multichannel Accelerograph Recorder System that;

- 1.1 can function normally in extreme environmental elements of humidity, dust and temperature.
- 1.2 is a standard production model used by leading networks for recording strong motion.

2 APPLICABLE SPECIFICATIONS / STANDARDS / CODES

- 2.1 Specifications and standards referenced in this document form a part of this specification.
- 2.2 Upon written request, manufacturer shall submit certification that units and accessories furnished to meet specifications of this document comply with requirements of following standards/codes.
 - 2.2.1 FCC § 15 Class A for industrial/commercial electrical equipment.
 - 2.2.2 Underwriters Laboratories (UL) standard 50 for electrical equipment safety enclosures.
 - 2.2.3 UL standard 508 for Industrial Control Equipment.
 - 2.2.4 UL standard 94-V2 for Flammability of Plastic Materials for internal Parts.
 - 2.2.5 National Fire Protection Association (NFPA) code 70 for electrical conductors, equipment, signaling and communications conductors and raceways.
 - 2.2.6 Ingress Protection (IP) standard 67 for watertight integrity of electrical enclosures.
 - 2.2.7 National Electrical Manufacturers Association (NEMA) Type 6 for electrical enclosures.
 - 2.2.8 NEMA Type 4 for system enclosures.
 - 2.2.9 Latest Electro Static Discharge Association (ESDA) standard S541 for electrical components and enclosures.
 - 2.2.10 Unified Thread Standard (UTS) Class Unified Fine (UNF) 28 for screw threads.

3 REQUIREMENTS

3.1 GENERAL OPERATION

- 3.1.1 Recorder shall remain in a standby condition, and start recording when actuated by strong shaking or manually activated for test purposes. After actuation, it shall stop recording after a set time or after shaking stops, and return to the standby condition, ready to record another earthquake without servicing or attention. Recording shall stop without overwriting previous events when memory becomes full.
- 3.1.2 Unit shall have 6 to 18 channels capability.
- 3.1.3 Unit shall be battery powered with solid state memory and remote Accelerometers.
- 3.1.4 Shall be 18-bit or higher AD conversion, with appropriate anti-aliasing filtering
- 3.1.5 Shall be able to be installed and field-calibrated with a minimum of adjustment.
- 3.1.6 Shall consist of remote Accelerometers cabled to a central Recorder
- 3.1.7 Record accurately strong shaking (as high as 4g) without data loss or damage.

3.2 SYSTEM CHARACTERISTICS

- 3.2.1 The noise level of the system (including Accelerometer, Recorder and interconnection) in the absence of shaking shall be a maximum of 0.030 mg (i.e., one count of an 18-bit system with 4g maximum acceleration).
- 3.2.2 Frequency response of the complete transducer-Recorder system shall be flat to within 1% from 0 to 40 Hz, and full documentation shall be provided to allow for accurate instrument correction of the data recorded. Any effects on the recorded data from signals or noise at frequencies higher than 100 Hz shall be <0.030 mg.
- 3.2.3 Recorder and Accelerometer shall reject spurious electronic and electromagnetic noise and interference from radio frequencies (RFI) as well as AC & other frequencies.
- 3.2.4 Recorder, Modem and Accelerometer shall also include effective protection against power and phone line surges and electrostatic discharge (ESD) effects.

3.3 ACCELEROMETERS

Accelerometers are to be uniaxial or borehole force-balance type meeting the following specifications;

- 3.3.1 **Operating Acceleration Range:** $\pm 4g$; full-scale output voltage of Accelerometer shall match the full-scale input of the Recorder.
- 3.3.2 **Accelerometer Frequency Response (Bandwidth):** Natural frequency of the unit shall be >45 Hz.
- 3.3.3 **Linearity:** $\pm 1\%$ or $1000\mu g/g^2$ error from negative to positive full scale.
- 3.3.4 **Accelerometer Noise:** <0.03 mg from 0 to 100 Hz.
- 3.3.5 **Cross-axis Sensitivity:** $\leq 1\%$ g/g.
- 3.3.6 **Temperature Effects:** <2% over the required operating temperature range of 0 to 150°F (-20 to 70°C). Zero point thermal drift shall be <500 $\mu g/^\circ C$.
- 3.3.7 **Function Testing:** Accelerometers shall produce calibration voltages during static tilt tests on all channels to allow verification of sensitivity constants. Accelerometer operation shall be verifiable via signal offset in response to signal command issued from the Recorder.
- 3.3.8 **Accelerometer Zero Output (Zero Adjust):** Adjustable to 0, $\pm 10mg$ after field installation to either a vertical or horizontal surface. Accelerometer zero value shall be stable over time, without steps or other changes during recording. Accelerometer zero adjustment mechanism, if present, shall lock securely so that the Accelerometer output resumes the pre-event zero level after earthquake shaking. If auto-zeroing of DC level is possible, it shall have the ability to be deactivated.
- 3.3.9 **Electrical Connections:** All electrical connections shall pass through sealed Military Spec "MS" type connectors. Signal and power commons shall be electrically isolated from the enclosure and the cable shield connections.
- 3.3.10 **Remote Operation:** Accelerometer must operate, without degradation of performance, up to 2000 feet (610 m) from the Recorder using standard cable with stranded 22 AWG gauge conductors. Each Accelerometer shall not require more than 4 twisted shielded pairs with individual drain wires.

- 3.3.11 Uniaxial Accelerometer Enclosure:** Accelerometer enclosure shall be <45 inches³ (740 cc), crush-resistant (able to withstand 30 lb weight dropped from 3 feet), resistant to EMI/RFI, moisture proof (able to withstand occasional submersion in water; NEMA 6/IP67) and corrosion resistant, with a rigid mounting base, to match SMIP standard mounting plate detail, attached. Enclosure shall be mountable to vertical or horizontal surfaces, and be able to sense vertical or horizontal motion in either position. Direction of positive acceleration shall be permanently marked on the outside of the enclosure.
- 3.3.12 Borehole Accelerometer Enclosure:** Package for deployment in a 4-inch ID cased borehole, containing three orthogonal accelerometers, two horizontal and one vertical (parallel to cylinder long axis). Enclosure shall be a 3 ±0.01 inches diameter 316 stainless steel case, 12 to 16 inches long. Enclosure top to be flat with centered, sealed connector for attachment of the removable downhole cable assembly connector. Enclosure bottom to be flat with a centered threaded 1/2 inch long stud, 3/4-16 UNF-28 thread, or equivalent. Enclosure to be resistant to EMI/RFI, sealed, and waterproof to withstand 800 psi. Enclosure to include a clearly visible permanent mark on the exterior related in a fixed way to the orientation of the internal horizontal Accelerometers.

3.4 CENTRAL RECORDER;

The central recording unit of the system shall be based on Recorder modules of 3 to 6 channels per module and be configurable by adding or deleting Recorder modules. All Recorder channels shall have unity gain or selectable gain in fixed steps, and meet the following specifications;

- 3.4.1 Sampling:** Recorded data sampling rate shall be 200 samples per second per channel. Anti-alias filtering of the analog signal from the Accelerometers or extraneous sources shall meet System Characteristics noise specification (see 3.2). Channel-to-channel sampling to be synchronized to within 0.2 msec.
- 3.4.2 Recorder Noise:** During normal operation, and when the Recorder transitions from the standby state to recording operation, the noise level shall not exceed the System Characteristics noise specification (see 3.2).
- 3.4.3 Temperature Effects:** <2% over required operating temp range of 0 to 150°F (-20 to 70°C).
- 3.4.4 GPS Timing:** Recorder shall record sample time information from the internal or external GPS receiver in the event header and in each file data block. Recorder shall also include an internal clock that is accurate to within 1 minute per month in the absence of GPS. Duty cycling of the GPS receiver shall be settable from 0% to 100%. Time and amount of last GPS update, GPS status information, and time-averaged location information (latitude, longitude and elevation) shall be available from the event header and via a status command. GPS receiver shall update internal clock when drift is greater than 0.5 msec. GPS antenna and receiver shall be locatable up to 1000 feet (300 m) from the Recorder without performance problems. Unit shall be delivered with 150 feet of antenna cable.
- 3.4.5 Event Run Time:** Pre-event run time shall be adjustable from 1 to 30 seconds. Post-event hold-on time shall be adjustable from 10 to 60 seconds.
- 3.4.6 Triggering:** Declaration of a triggered condition to depend on the acceleration (within the 0.1 - 12 Hz frequency band) and channel trigger voting. When the acceleration on a specified

channel exceeds the trigger threshold level specified for that channel, that channel's specified number of votes is added to the total votes for trigger. When the total number of votes reaches the minimum specified for triggering, a trigger condition is declared, and recording is to begin at the start of the next second. The triggering signal from another Recorder (see 3.4.18) is to be treated as a voting channel signal. Once a triggered condition is declared, recording shall continue until after the detriquer condition is met, dependent on the continuing motion and the channel detriquer voting. When the acceleration on a channel no longer exceeds the detriquer threshold level specified for that channel, continuously for the number of seconds specified by the post-event run time, that channel's specified number of votes is added to the total votes for detriquer, for as long as that condition continues. When the total number of votes reaches the specified minimum for detriquer, a detriquer condition is declared, and recording shall stop at the start of the next second. The signal from another Recorder (see 3.4.18) is to be treated as a channel signal with the exception that the post-event run time is not to be applied. For all channel signals, trigger and detriquer threshold levels shall be independently adjustable from 0.1 mg to full-scale. The number of votes for each channel shall be settable from 0 through 5 for both trigger and detriquer. The total number of votes required to trigger or detriquer the Recorder shall be independently settable from 0 through 9.

- 3.4.7 Function Tests:** Under user control, Recorder shall generate test signal commands to the Accelerometers to allow verifying Accelerometer operation from the recorded data. Recorder shall accommodate and record tilt tests on all 3 axes to allow calibration of the sensitivity constants of the Accelerometers.
- 3.4.8 Diagnostics/State of Health Monitoring:** Upon power up, and under user control at other times, Recorder shall perform internal self-checks and diagnostics to verify proper operation. Under user control, Recorder shall also provide, without generating an event, amount of available memory, firmware version number, timing, battery voltages, recording parameters and Accelerometer output levels (ambient and with offset signal applied). All Recorder configuration and operating parameters shall be written into a retrievable text file with a single command.
- 3.4.9 Data Storage:** A minimum of 60 minutes of data per channel shall be recorded, stored on standard memory cards (e.g., PC CARD, USB Flash Drive) readable by laptop PCs (MS® Operating System). Files on memory cards shall be individually deletable as well as globally deletable.
- 3.4.10 Batteries:** Entire system shall be powered by sealed internal and/or external 12-volt rechargeable DC batteries. Lithium batteries (if any) shall have a sealed stainless steel case. All batteries shall have the capability to be replaced without soldering.
- 3.4.11 Battery Charging:** Recorder shall include AC charging circuitry for maintaining the charge of the internal and/or external main batteries. Charger must be able to charge a completely discharged battery, and charging voltage and current shall be held within battery manufacturer guidelines.

- 3.4.12 Recovery after Loss of Power:** In the event of main battery failure, Recorder shall automatically return to normal operation (i.e., able to trigger and record data) once power is restored, without affecting retrievability of previously recorded data. In the event of long-term power loss, recorded data shall be preserved in memory for at least 30 days without affecting data retrievability.
- 3.4.13 Power Consumption:** Total power consumption at standby shall be <20 watt-hrs/day per channel (at 12vDC nominal), including power for the accelerometers, power for the GPS timing receiver with 5% duty cycling, and power for the modem (see 3.5.2) in the absence of calls. Internal charger shall be capable of charging sufficient external batteries for a minimum of 4 days autonomous operation.
- 3.4.14 Recorder Enclosure:** The Recorder enclosure shall be made of engineering plastic, or galvanized or stainless steel, resistant to EMI/RFI, NEMA 6/IP67 rated, and mount in the System enclosure. All electrical connections into the Recorder enclosure shall be through sealed connectors, or cables running through sealed strain reliefs. Normal maintenance procedures shall not require opening the Recorder.
- 3.4.15 Deployment:** Installation of system enclosure shall require no onsite assembly/soldering.
- 3.4.16 Electrical Connections:** System enclosure shall include a standard 125vAC, 20amp receptacle or power strip with adequate outlets for Recorder power and at least one additional AC outlet for test equipment. The electrical connections for the cables from the external accelerometers and the external timing device shall be plated to resist corrosion and require no soldering or crimping of terminal lugs.
- 3.4.17 Interconnection of Recorders:** Recording units shall be interconnectable with up to 5 other central recording units, located up to 4500 ft (1400m) apart, using standard cabling. Each recording unit shall provide a trigger signal for triggering other systems, which goes high on declaration of trigger by the Recorder and is held high until detrigger conditions are met on the Recorder (trigger and de-trigger declarations occurring as specified in 3.4.6).
- 3.4.18 System Enclosure:** The system enclosure shall be wall-mountable, galvanized or stainless steel, crush resistant (able to withstand a 30lb dropped from 3 feet), NEMA-4 rated, complete with provisions for locking (using standard padlocks with 5/16" shackle). System enclosure shall provide adequate space for Recorder, associated components, and batteries needed for the required autonomous operation period (see 3.4.13). When fully equipped, the system enclosure shall have a maximum weight of 100 lbs (45 kg), exclusive of batteries, and shall be <5 Ft³. (0.15m³) in size.

3.5 COMMUNICATION WITH RECORDER

- 3.5.1 Remote Communication:** Remote interrogation of the system state-of-health shall be available via the included 56 kbps or faster telephone modem (or optional cellular modem or TCP/IP adapter) without retrieving or altering the data in memory. The state-of-health information shall include battery voltages, battery charging status, GPS system status, amount of memory used, event count, and accelerogram parameters (including peak values, event length, time of trigger and channels causing trigger). The remote access shall allow performing all functions that the local on-site connection can perform (including data retrieval,

upgrading the firmware, and functional and diagnostic tests) and shall include protection against unauthorized access. All interrogation and control shall be by means of ASCII-character commands from a PC in terminal mode.

- 3.5.2 Modem Power Control:** Modem (internal or external) shall normally be not powered, or in the absence of calls, use <3 watt-hrs/day at 12vDC. Modem, when active, shall use <225mA at 12vDC nominal. The Recorder shall, upon triggering, power the modem and initiate call-out within 5 seconds. For incoming calls, a ring-detect provision shall turn on the modem and answer the call. Modem control shall include ≥ 5 specifiable windows of time during which the modem and optional external cellular phone are powered. Modem and communication equipment shall remain powered for the duration of the call.
- 3.5.3 Triggered Communication:** Upon being triggered, Recorder shall auto-dial a remote computer, initiating dialing within <5 seconds. Recorder shall identify the name of the event file causing it to call-out. If the communication is unsuccessful, the unit shall re-attempt to communicate after successive time intervals doubling in length, starting at 15 seconds and increasing to 3 days, and maintain a retrievable log of the communication attempts. Recorder shall declare communication success upon receipt of a specific command from the remote computer.
- 3.5.4 Alarm Communication:** Recorder shall call a remote computer (see 3.5.3) upon detecting selectable equipment malfunctions (including at least low battery level and loss of AC) and indicate the reason for the call. Recorder shall also call out at a specifiable time or when user specifiable channels exceed specifiable "alarm" threshold levels.
- 3.5.5 Triggered Data Retrieval:** Recorded data shall be retrievable locally or remotely via modem, using a desktop or laptop PC and communication software using terminal mode and standard file transfer protocols (Xmodem, Ymodem, Zmodem), allowing data from the Recorder to be transferred rapidly to standard PC media. During data retrieval and interrogation, the system shall remain operational and record any events that occur. Peak acceleration values shall be updated during the event and be available for retrieval while the event is still being recorded. Data retrieval from memory shall yield an exact copy of the file, and not cause stored data to be erased. Vendor shall provide specification, operating system and interface software for the MS® Operating System Recovery computer.
- 3.5.6 Data Transfer:** Rate Data transfer rate (per three channels) shall be such that 1 minute of three-channel data is transferred in <1 minute (that is, on a per-channel basis, a transfer time of <20 seconds/channel for 60 seconds of data). Compression algorithm (if any) shall have a data-reconstruction error of <1 LSB from 0Hz to the Nyquist frequency.
- 3.5.7 Data Handling Software:** Data review and retrieval software shall be provided which operates on a MS® Operating System PC and provides for field review of data as well as output in an event file with well-documented format. Software shall include a stand-alone program to display and print the event header information in a summary form. Full documentation of the header and data layout in the raw event file shall be provided. File conversion software shall be provided (with documented source code) to convert the event

file from native format to COSMOS Volume 0 Strong Motion Data Format, v 1.20
(<http://www.cosmos-eq.org>).

- 3.5.8 Continuous Data Transmission:** Simultaneously with other operations, instrument shall be capable of continuous transmission of ≥ 6 channels in a digital data stream using full duplex real-time communication. Unit shall use a fully documented protocol compatible with modern communications (Frame Relay, DSL, TCP/IP, etc) for input into a digital seismic monitoring system (e.g., Earthworm, etc.).

Appendix A

The following units have met the CGS/DGS Central-Recording Multichannel Accelerograph System Requirements and are currently in use by the California Strong Motion Instrumentation Program (CSMIP), California Geological Survey.

Model and Manufacturer:

K2-12 (12 channel) and Mt Whitney (18-channel) Accelerograph Systems

Kinematics, Inc.

322 Vista Avenue

Pasadena, California 91107

(626)795-2220

www.kinematics.com

Model and Manufacturer:

130-MC12A (12 channel) and 130-MC18A (18 channel) Accelerograph System

Refraction Technology, Inc.

1600 10th St., Suite A

Plano, Texas 75074

(214)440-1265

www.reftek.com

4 October 2007