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امورتدوين استانداردها

مشخصات فنی خرید

شتاب نگارزلزله در سیستم قطع خودکار ایستگاههای گاز شهری

Earthquake accelerometers in automatic shut-off system of urban gas stations

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ابلاغ مصوبه هیأت مدیره

مدیر محترم پژوهش و فناوری

باسلام،

به استحضار می‌رساند در جلسه ۱۷۴۳ مورخ ۱۳۹۶/۵/۲۲ هیات مدیره ، نامه شماره گ۹/۰۰۰/۶۳۲۷۳ مورخ ۹۶/۵/۱۷ مدیر پژوهش و فناوری درمورد تصویب نهایی استانداردها به شرح زیر مطرح و مورد تصویب قرار گرفت .

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1- SCOPE

This standard provides minimum requirements for procurement specifications of earthquake accelerometers in automatic shut-off systems of urban gas station. The specifications provided in this standard shall also be applied for the maintenance of accelerometers used in automatic shut-off systems. Accelerometers are one part of automatic shut-off system and this standard provides specifications only for accelerometers. For other parts of the shut-off system, all other standards and codes of NIGC shall be met.

2- REFERENCES

a. Instrumentation Guidelines for the Advanced National Seismic System, (2007), U.S. Geological Survey and ANSS National Implementation Committee
b. Guideline for ANSS Seismic Monitoring Of Engineered Civil Systems, (2005), UGSG, Open file Report 2005-1039
c. IEC60529, Degrees of Protection Provided by Enclosures (IP Code), (2004), National Electrical Manufacturers Association
d. IEC61326, Electrical Equipment for Measurement, Control And Laboratory Use –EMC Equirements (2002), International Electrotechnical Commission, Switzerland
e. EN55022, Information Technology Equipment-Radio Disturbance Characteristics-Limits and methods of measurment, (2006) European Standard

3- DEFINITIONS

3-1- Sensor

A sensor is a device that detects changes in physical quantities such as vibration, displacement, pressure, temperature, humidity and provides a corresponding analog or digital electrical output to changes.

3-2- Accelerometer

Accelerometer or strong-motion sensor is a sensor that measures ground motion acceleration.

4- TYPE OF ACCELEROMETERS

4-1- Simple Pendulum Accelerometer

Simple pendulum accelerometer works as an open loop accelerometer. This method is widely used in the manufacturing of MEMS (Micro Eloctro-Mechanical Sensors) accelerometer.

4-2- Force-balanced Accelerometer

In such accelerometer, external force that applied to the mass of accelerometer is compensated by an equal electromagnetic force in the opposite direction in a way that the mass remains stationary. In this approach, moving of the mass is prevented with the aid of a feedback circuit.

4-3- MEMS

MEMS (Micro Electro Mechanical Sensors) accelerometers are microelectromechanical systems that are built onto semiconductor chips and measure acceleration. It is possible to use force-balance or MEMS accelerometer for shutting off the gas in earthquakes provided that the specifications of Section 6 of this standard are met.

5- SPECIFICATIONS OF ACCELEROMETER

The minimum acceptable accelerometer performance specifications for applying in automatic gas shut-off devices are represented as bellow:

5-1- Number of Recording Axes

Accelerometers used in shut-off systems shall record ground acceleration in three orthogonal axes. These components shall be independent to each other.

5-2- Clip-level

The maximum recordable acceleration by accelerometer is called clip level. Clipping level depends on the accelerometers mechanics and digitizer specifications. The clip level of the accelerometers shall be at least 1.5 times the ground acceleration (1.5g). This value is obtained from statistical analysis of strong motion data recorded in Iran and specific application of accelerometers for shutting off the gas stations. The maximum recorded PGA

in Iran, regardless of soil condition, is approximately 1.0g. On the other hand, the common threshold values of PGA for shutting off the gas are much less than 1.0g. Thus, the value of 1.5g for clip-level introduces a conservative value in this regard.

5-3- Self-noise (RMS)

All electrical components and electronic accelerometers generate noise. In the absence of external and ambient vibrations, the self noise is also available. This parameter is expressed as the root mean square (RMS) of measured noise. The procedure for calculation of RMS is as follow (ANSS, 2007):

- using time series without weightening
- using Welch method for calculation of PSD
- using time history pieces with an overlap of 50%
- using Hanning Window function
- the minimum number of time history pieces shall be equal to 10
- cutting of the time history so that the length of each pieces is an integer number of second

The RMS of accelerometer self-noise shall be less than $100\,\mu g/\sqrt{Hz}$. Thus, the minimum acceptable RMS of noise shall be:

$$RMS\,of\ Noise = self\ noise \times (frequency bandwidth)^{0.5}$$
$$= 100 \times \sqrt{25} = 500\,\mu g = 0.490\,cm/s^2$$

It shall be noted that clip level of 1.5g and dynamic range of 85dB will fulfill this criterion. However, the RMS of self-noise of the accelerometers shall be determined by an acceptable method in order to compute the dynamic range of the accelerometers.

5-4- Accelerometers Dynamic Range

Dynamic range is the ratio of the largest to the smallest recordable signal. The smallest

recordable signal depends on the accelerometers self-noise and digitizer resolution. The largest recordable signal depends on the clipping level of the accelerometers. Dynamic range is usually expressed in dB.

$$Dynamic\ Range = 20 \times \log_{10}\left(\frac{clip\ level}{RMS\ of\ self-noise}\right) \qquad (dB)$$

The minimum value of dynamic range for shut-off accelerometer shall be 85dB. Considering the minimum clip level of 1.5g, the maximum RMS of accelerometers self-noise shall be less than 0.08 cm/s^2. This value of self-noise is much less than common power of ambient and mechanical noise sources. Indeed, the threshold value of PGA required for shutting off the gas is much more than the valued of 0.08 cm/s^2.

5-5- Accelerometer Resolution

The minimum recordable vibration change by the accelerometer is called accelerometer resolution. This parameter is a function of digitizer sensitivity and usually expressed in bit. Digitizer is a device that converts analog signal (voltage) to digital signal which is commonly placed in the accelerometers box. Therefore the output of accelerometer will be digital.

In a accelerometers with *n* bit resolution, one bit is usually kept for the sign of the voltage signal. The minimum measurable voltage or acceleration is equal to:

$$\text{minimum measurable voltage} = \frac{\text{maximum measurable voltage or acceleration range}}{2^{n-1}}$$

The resolution of the accelerometers is the resolution of analog-to-digital convertor or digitizer of the accelerometers. Considering the clip level value of 1.5g and dynamic range of 85 dB, the minimum resolution of accelerometer shall be 16 bits. In this regard, the minimum resolvable acceleration is:

$$1.5 \times 981/(2^{16-1}) = 0.04\ \ cm/s^2$$

which is less than acceptable noise level of 0.08 cm/s^2.

5-6- Corner Frequency (Force-Balanced)

In force-balanced accelerometer, corner frequency specifies the point where the response begins to decline. This parameter is a function of natural frequency of the system. The corner frequency of accelerometers shall be at least 100Hz. This value is to ensure that the corner frequency of accelerometer is far enough from desired bandwidth of the accelerometers.

5-7- Bandwidth Desired

Frequency range for a specific application is called desired bandwidth. This frequency range shall be less than flat response frequency bandwidth of acceleration.

Flat response frequency bandwidth is the range of ground motion frequencies that can be accurately reproduced by the resulting digital data (Figure 1). As a definition, this limit is usually considered as the range between -3 dB points less than maximum frequency response of the accelerometer.

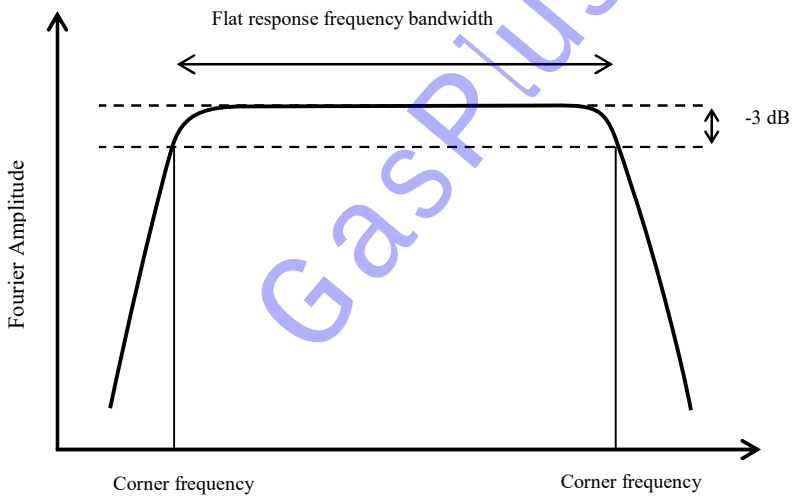

Figure 1.Frequency response of accelerometer and its parameters

The range of accelerometer‘s bandwidth shall contains the frequencies between 0.01~ 25 Hz. However, it is recommended that the upper bound of this range be 50Hz.

The minimum sampling rate of shut-off accelerometers shall be 50 sps.

5-8- Generator Constant at Output

Generator constant at output is the voltage generated by the accelerometer for 1 m/s or one time of gravity acceleration. This parameter is a function of vibration frequencies and shall be measured at 1 Hz. The generator constant at output for shut-off accelerometers shall be more than 1.0V/g.

5-9- Sensitivity Accuracy

The deviation of recorded acceleration from the true acceleration is called sensitivity accuracy or sensitivity error. The sensitivity error of the accelerometer shall be within 1% deviation from true value.

5-10- Temperature-Induced Sensitivity Errors

Fluctuations of temperature can have influence on the sensitivity of the accelerometers. The temperature induced sensitivity error shall also be less than 0.5% over -20 to +40 °C.

Anyway, the total sensitivity error (temperature and other sources) of the accelerometer shall be limited to 1%.

5-11- Total Harmonic Distortion

The total harmonic distortion (THD), of a sensor is measurement of the existing harmonic distortion and defined as the ratio of the power of the fundamental frequency to the sum of the powers of all harmonic components. The THD for shut-off accelerometers shall be less than -35dB. The measurement is most commonly done as the ratio of the RMS amplitude of the fundamental frequency to RMS amplitude of a set of other harmonic frequencies. To measure THD, the accelerometer shall be excited with a specific frequency and calculation is done according to output of the accelerometer.

5-12- Cross Axis Sensitivity

Cross axis sensitivity is a measure of how much output is seen on one axis when acceleration is imposed on a different axis, typically specified as a percentage or dB. The coupling between two axes results from a combination of alignment errors, etching inaccuracies, and circuit crosstalk.

Cross-axis sensitivity is defined as:

$$CrossAxisSensitivity = 20Log_{10}\left(\frac{\sqrt{A_y^2 + A_z^2}}{A_x}\right)$$

Where A_x is the measured sensitivity in measuring direction, A_y and A_z are the measured sensitivities in cross-axis directions. Sensitivities used in cross-axis calculation should be in the cm/s^2 unit. The value of CrossAxisSensitivity shall be less than -35dB. In other words, if the acceleration of 1g is exerted to one axis of the accelerometer, the root square of acceleration measured on two other axes shall be less than 0.018 g.

5-13- Linearity

An ideal accelerometer is one that behaves as a linear system so that if we e.g. double the input, the output will also be doubled. In other words, linearity specifies a linear relationship between input and output of the accelerometer. The linearity is the maximum deviation of output from a best fit straight line in static tilt calibration and measured in dB. The linearity error of accelerometers shall be less than -35dB.

5-14- Clip Recovery

The time duration required for accelerometer to start recording after experiencing vibration higher than clip level shall be less than 1.0 second. This is to ensure that accelerometer is operational after a large shock.

5-15- Expected Lifetime

In the lifetime of the accelerometers, the characteristics of accelerometer shall remain in the limits specified in this standard. Minimum expected lifetime of accelerometers shall be ten years.

5-16- Radio-frequency Interference

When the instruments are located in environments with radio interference, there shall not be any detectable effect on the output signal. RFI performance of the accelerometer shall be tested, as per NIGC request, according to IEC61326(2002).

5-17- Operational Temperature Range

According to the local environmental condition of Iran, the shut-off accelerometers shall be operational over -20~60 °C.

5-18- Enclosures Protection

According to IEC 60529, the Enclosures Protection of accelerometers shall be 67 (IP67).

5-19- Timing System

Accelerometers are equipped with internal timing system in addition to GPS for synchronization of different stations.

Summary of all required specifications is provided as follow:

Table 1: Minimum acceptable accelerometer performance specifications

No.	Performance Metric	Value	Definition Item
1	Number of recording axes	3	5-1
2	Clip-level	1.5g	5-2
3	Self-noise (RMS)	$< 100\ \mu g / \sqrt{Hz}$	5-3
4	Accelerometer Dynamic Range	>=85dB	5-4
5	Accelerometer resolution (A/D)	>=16 bits	5-5
6	Corner Frequency (Force-Balanced)	>=100 Hz	5-6
7	Bandwidth desired	0.01 Hz ~ 25 Hz	5-7
8	Generator Constant at Output	≥1.0V/g	5-8
9	Sensitivity Accuracy	<1%	5-9
10	Temperature-Induced Sensitivity Errors	<0.5% over -20 to +40°C	5-10
11	Total Harmonic Distortion	<-35 dB	5-11
12	Cross axis sensitivity	<-35 dB	5-12
13	Linearity	<-35 dB	5-13
14	Clip recovery	<1 sec	5-14
15	Expected lifetime	10 years	5-15
16	Radio-frequency interface	According to IEC61326(2002)	5-16
17	Operational Temperature Range	-20~60 °C	5-17
18	Enclosures Protection (IP)	67	5-18
19	Worst time keeping error with regular GPS locks	<2msec	5-19

6- ACCELEROMETER ANALYTICAL AND EXECUTIVE SPECIFICATIONS

The shut-off accelerometer unit shall, inter alia, be capable to:

- Compute the Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV), Cumulative Absolute Velocity (CAV), Spectral Intensity (SI) and send these parameters to distant control center and/or save them on an internal storage
- Send shut-off command to shut-off valves based on customized shut-off criteria
- Receive shut-off command from distant control center and send it to shut-off valves
- Receive shut-off criteria from distant control center
- Save continuous acceleration waveform for at least 15 days on an internal storage
- Have accurate internal timing system

7- ACCELEROMETER CALIBRATION

The digital output of accelerometers is a set of integer numbers. For converting these numbers to physical unit of acceleration (m/s^2), it is necessary to measure the output of a accelerometer in response to an accurately known input at a specific frequency. Indeed, cross axis error of the accelerometer shall also be determined and required correction be applied at the output of the accelerometer. Method of calibration shall be provided by the manufacturer and be approved by NIGC. The period of calibration shall be specified by manufacturer and be approved by NIGC.

8- TECHNICAL DOCUMENTATION

8-1- The accelerometer vendors shall provide all specifications listed in table 1 in the form of technical documents of accelerometer. These documents shall be delivered inside

the accelerometer packages.

8-2- The calibration certificate of each accelerometer shall be represented in the form of a sheet with accelerometer. Indeed, the method of calibration shall be represented in the technical documents.

8-3- The accelerometer vendor shall described the output format of acceleration data in the technical documentation. It is preferred that output of accelerometers be provided in a standard format.

8-4- The specifications of output cables and the map of output connection pins (connectors) shall be represented in the technical document.

9- ACCELEROMETER ACCESSORIES

The items listed in this section are minimum accessories that shall be packed with each accelerometer. Other additional accessories may be provided by the vendor.

9-1- Connection cables

Connection cables of the accelerometer must be able to transmit digital data reliably up to a distance of at least 100 meter.

9-2- Connection and Controlling software of Accelerometers

Connection and controlling software shall be provided by the vendor as a part of accelerometer package.

10- INSTALLATION REQUIREMENTS

- Accelerometer shall be installed in a way that records the motions of the earth rather than response of the structures.

- For protecting the accelerometers and reducing the environmental noise, the accelerometers shall be installed at the depth of at least one meter beneath the ground surface.
- Accelerometers shall be installed in way that they can withstand the acceleration as much as 3.5g in three orthogonal directions.

11- INSPECTION AND TESTING

In addition to manufacturers' validation testing for their own purposes, verification testing of performance shall be conducted as part of the procurement process. NIGC may test samples of all items in the above mentioned specifications that are applicable to that particular accelerometer. Random and targeted acceptance tests of instruments (the deliverables) may be performed by NIGC to verify ongoing compliance with specifications, testing all or portions of applicable specifications as deemed appropriate by NIGC.

The intention of vendor and NIGC testing described here is to reduce the lifecycle cost of shut-off accelerometers and to verify their performance. Therefore, significant initial expense is tolerated where it is likely to reduce long-term expense, failures, and uncertainties in performance, reliability, or the validity of the data for their intended uses.

11-1- Validation Testing

Validation testing by the manufacturer checks whether the product design satisfies or fits the intended usage. Such high-level testing is generally part of the design process and as such may be used by vendors to prepare for performance verification tests described later. Such validation testing may be part of the vendors' research and development, pre-qualification, and manufacturing-development processes leading to their confidence in their product.

11-2- Performance Verification Testing

Verification testing confirms that products meet specified performance requirements. In

the NIGC context, this should be a formal step in which vendors complete formal performance verification testing, under close NIGC observation, of final versions of two randomly-selected accelerometers. Test specifications should be prepared in advance of any procurement and be approved by NIGC. All resulting data and analyses should be provided for NIGC in sufficiently complete form that NIGC can analyze the test data and confirm test results.

It is recommended that two or more test specimens be selected at random from a batch of eight or more final manufactured copies of final versions of the proposed accelerometer. NIGC requires that tests be witnessed in person by NIGC staff or their representative(s) and possibly recorded in video and sound (by NIGC) for documentation and external review. NIGC may require that original test data be supplied to the witness for direct transfer to NIGC at the time of the testing.

11-3- Acceptance Tests

Acceptance tests of randomly selected units may be performed upon delivery or shortly afterward to verify whether the components and systems meet NIGC contract specifications. If they do not: (i) the components/systems should be returned to the vendor for repair, (ii) additional units of similar manufacturing lots or serial numbers should be tested by NIGC, and (iii) if a pattern of vendor non-compliance emerges, that vendor may be considered substantially unresponsive in subsequent requisitions.