

भारतीय मानक

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अनुसरण और अवलोकन — प्रक्रिया संहिता

Indian Standard

CODE OF PRACTICE FOR INSTALLATION,
MAINTENANCE AND OBSERVATION OF THE
INSTRUMENTS FOR VIBRATION STUDIES OTHER
THAN EARTHQUAKES

ICS 17.160; 93.160

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FOREWORD

This Indian Standard was adopted by the Bureau of Indian Standards, after the draft finalized by the Hydraulic Structures Instrumentation Sectional Committee had been approved by the Water Resources Division Council.

The vibrations may be measured as displacement, velocity or acceleration with the help of displacement gauges, velocity pick-ups and accelerometers respectively. Displacement measurements require a stable reference structure close to the vibrating structure and it may be many a times impracticable to have one especially for hydraulic structures. Velocity pick-ups suffer from poor response to high frequency vibrations and are bulky for certain applications. The accelerometers hence are the most preferred. They are proven in respect of versatility, ruggedness, accuracy and dynamic response. Accelerometers employ piezoelectric elements, force balance techniques or strain gauge based elements. Therefore, the signal conditioners suitable for the particular type of accelerometers have to be provided. As regards data recording and data analysis a computerized signal analyzer with sufficient disk storage capacity completely replaces the earlier techniques of recording on multi-channel instrumentation tape recorders and analyzing on a tunable band pass filter type frequency analyzers. Battery operated signal analyzers are common now-a-days.

This standard covers requirements of the accelerometers, signal conditioning and signal processing equipment for the application of vibration studies.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated expressing the result of test or analysis, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

CODE OF PRACTICE FOR INSTALLATION, MAINTENANCE AND OBSERVATION OF THE INSTRUMENTS FOR VIBRATION STUDIES OTHER THAN EARTHQUAKES

1 SCOPE

Vibration studies are conducted on hydraulic machines viz. pumps, hydro-turbines, on civil structures viz. dams, divide walls, bridges, power houses, foundations and on other parts viz. gates, penstocks, trash-racks, etc. This standard recommends a versatile combination of the instruments essential for observation of vibrations arising from sources other than earthquake that is flow induced and operations of the machine. It further covers the details on installation of accelerometers and procedure for observations of the vibration with the help of associated instrumentation containing signal conditioner and signal processor.

2 INSTRUMENTATION

2.1 Accelerometers

2.1.1 Constructional Details

There are number of technologies which have produced accelerometers, however the technology employing piezoelectric material develops an electrical charge when subjected to dynamic stresses. In a piezoelectric accelerometer, a heavy mass (seismic mass) preloaded by a shift spring, rests on the stack of piezoelectric discs. When the assembly is subjected to vibration the mass exerts a dynamic force on the disc which develops a variable charge proportional to force and hence to acceleration. Figure 1 shows constructional details of an accelerometer.

2.1.2 Performance Characteristics

2.1.2.1 Sensitivity

A piezoelectric accelerometer is electrically analogous to a capacitor shunted by a high resistance and also a voltage source or a charge source. The piezoelectric accelerometer thus has two sensitivities viz. charge sensitivity and voltage sensitivity. The voltage sensitivity is expressed as mv/m/s and charge sensitivity as pc/m/s. These two are related by,

$$\text{Voltage sensitivity} = \frac{\text{Charge sensitivity}}{\text{Accelerometer capacitance} + \text{Cable capacitance}}$$

The charge output of accelerometer is independent of cable length however the voltage output depends upon the cable length. Therefore, the charge output is preferred and hence the amplifier associated with piezoelectric accelerometer is invariably a charge amplifier. Accelerometer sensitivity is generally of the order of 10 pc/m/s.

2.1.2.2 Frequency response

The frequency response is defined as the variation of accelerometer signal with reference to frequency of a sinusoidal vibration. The accelerometer signal is fairly constant over the desired frequency range. The natural resonance frequency of an accelerometer corresponds with natural frequency of the seismic mass. Up to a frequency of 1/5th of the natural resonance frequency the variation in accelerometer signal is generally within 6 percent.

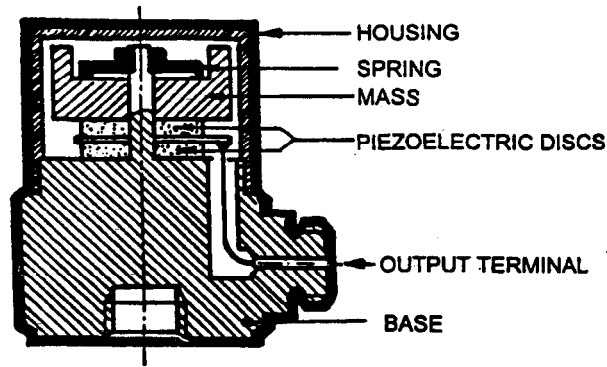
On the lower end of the frequency spectrum rather than accelerometer the charge amplifier's frequency response becomes the limiting factor. The phase response is one of the significant characteristics in respect of transient and shock performance of the accelerometer. The upper frequency limitation should be minimum of 1 000 Hz and beyond.

2.1.2.3 Dynamic range

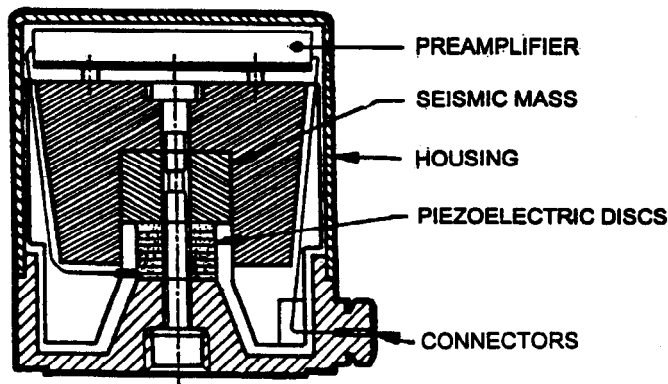
The dynamic range is the range of magnitudes of accelerations over which the accelerometer output is directly proportional to the acceleration amplitude applied. The lower magnitude is limited by the mounting, cable length, environmental conditions and amplifier noise level. The higher magnitude for continuous accelerations is much higher than the accelerations encountered in practice.

2.1.2.4 Sensitivity of accelerometers to unwanted parameters

The accelerometers are also sensitive to many other unwanted physical parameters viz. temperature, sound, strain at the base surface, magnetism and transverse accelerations. These sensitivities cause error in measurements. The acceptable sensitivities on these accounts are as follows:



GENERAL PURPOSE ACCELEROMETER



HIGH SENSITIVITY ACCELEROMETER

FIG.1 CONSTRUCTIONAL DETAILS OF ACCELEROMETER

Temperature sensitivity	1 pc/°C
Acoustic sensitivity	0.01 pc at 154 db sound pressure level
Surface strain sensitivity	0.03 pc/microstrain
Magnetic sensitivity	10 pc/Tesla magnetism
Transverse sensitivity	4 percent

2.2 Signal Conditioner

2.2.1 Configurational Details

The signal conditioner comprises of electronic circuits comprising of the preamplifier as charge amplifier, low pass-high pass filters runs, integrators and peak detectors, etc. These circuits are built around operational amplifiers. The frequency response and gains of amplifier, choice of acceleration, velocity and displacement are switch selectable. Signal conditioner is provided with meter indication for RMS, peak values and is powered through line supply or

built in battery pack. Figure 2 shows schematic of a signal conditioner.

2.2.2 Performance Characteristics

2.2.2.1 Amplification

The gain of the amplifier is expressed in mv/pc and with 1 mv/pc gain termed as 0 db, amplifier with gain variation of the order of 100 db is required.

2.2.2.2 Frequency response

The frequency response of the signal conditioner is adjusted by means of the low pass and high pass filters associated with the amplifier. The low frequency cut off at minimum 0.2 Hz and high frequency cut-off at minimum 1 000 Hz or beyond is required for the applications. The filter roll off, of the order of minimum 12 db/octave is required for sufficient rejection of unwanted frequencies.

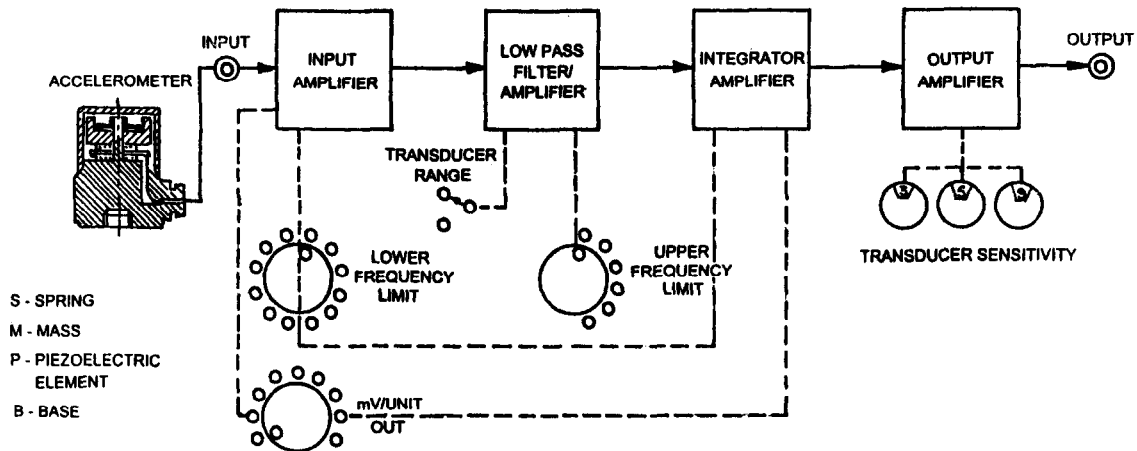


FIG. 2 PIEZOELECTRIC ACCELEROMETER AND SIGNAL CONDITIONER

2.2.2.3 Integration

The output of preamplifier corresponding to acceleration is integrated to produce output corresponding to velocity which when integrated in turn produces output corresponding to displacement. These integrators are, in fact, a pair of -20 dB/octave cut-off low pass filters so that they produce outputs exactly corresponding to velocity and displacement. These filters are built around operational amplifier as active filter for good accuracies.

2.2.2.4 Meter indication

The signal conditioner should be provided with panel meter indication of the vibration parameters for on-line monitoring and would also be helpful for setting up of instruments for experiments involving analyzers. The meter indication is both RMS and peak value selectable. The crest factor for RMS detector should be less than 3 and the time constant for the RMS as well as peak detector should be in the range of 1 to 10 seconds.

2.2.2.5 Dynamic range

The amplifier gain should be switch selectable, each setting corresponding to combination of range and sensitivity. The dynamic range would be most affected by noise level at the low end for the maximum sensitivity. A dynamic range of the order of minimum 50 dB would be required.

2.3 Signal Processor

2.3.1 Evolution

The aim of vibration measurements should be to assess peak or RMS value of the vibration parameters and the frequency at which they occur. Since the vibration

phenomenon would be random in nature to assess, its measurement needs to be carried out and measurement data analysed on line. The earlier vibration measuring equipment contained an electronic tunable band pass filter and frequency spectrum strip chart recorder connected to the accelerometer and the signal conditioner. The signal conditioner with meter indication still prevails owing to suitability for routine monitoring applications. However, the electronic band pass filter and frequency spectrum recorder have now been replaced by computerised signal processor equipment. This standard elaborates only the signal processor, being relevant today.

2.3.2 Configurational Details

The signal processor is a microcomputer based equipment. It essentially consists of analog input section, CPU, CRT display, floppy drives and output section and keys to perform various functions under microprocessor control. The microcomputer with the help of stored programmes and functional keys controls the operation of the equipment besides conducting the signal processing. A multi-channel inputs two or four channel versions with multiple display is required for the application. Figure 3 shows schematic of a signal processor.

The recorder should have a filter for cancellation of electrical noise which is common in most power plants and at blasting sites. The recorder should have RS-232 port for data transfer.

2.3.3 Performance Characteristics

2.3.3.1 Analog input characteristics

A multi-channel (two or four channels), direct coupled inputs for simultaneous data acquisition is required.

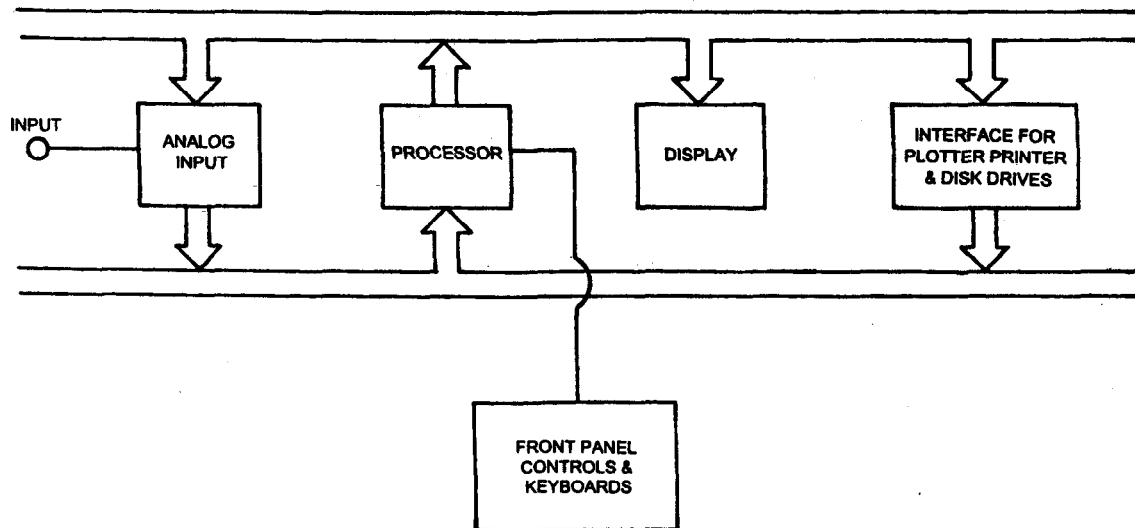


FIG. 3 SCHEMATIC OF SIGNAL PROCESSOR

The inputs are direct coupled so that the lowest frequency in the measured vibrations not be limited. The input impedance of the order of mega ohms or greater and frequency response beyond 1 000 Hz is required for the applications. The input section needs to contain an antialiasing filter with facility for selection of cut off frequency with keys.

2.3.3.2 Analysis functions

The following analysis functions are often required in vibration assessment work.

- a) Amplitudes and peaks in time domain.
- b) Instantaneous and average frequency spectrum, cross spectrum, coherence, transfer function, power spectral density.
- c) Orbits, nyquist diagrams, probability density functions. auto-correlation, cross-correlation, time averaging.
- d) Arithmetic and calculus functions.

2.3.3.3 Other processing facilities

- a) Weighting functions for frequency spectrum.
- b) Transient capture and storage with preset delays.
- c) Selection of frequency range and amplitude range.
- d) Display formatting with markers, cursors, text editing, etc.
- e) Manual control by keyboard and disk data processing.

2.3.3.4 Storage and presentation of results

The results of processing available on CRT display

should be stored on floppy diskettes/hard disk and should be presented on a plotter or printer.

3 POINTS OF VIBRATION MEASUREMENTS

The vibration measurements are not always possible on the most pertinent parts viz. runner blades or wicket gates of a hydro-turbine, bearings in rotating parts or flapper of a valve, etc. Therefore, bearing housing, valve body, etc, are considered measurement points. For measurement of gate vibrations and penstock vibrations, the accelerometers are installed directly on them for example, on a centrally placed girder of the gate.

For vibrations measurement on bridges, bridge piers, power houses, divide walls, etc, the points selected are generally at the centre of the walls, centre of girders, unsupported ends, etc, regardless of response of the structure to periodic or random stimuli. However, an approximate estimate of the response of the structure helps in deciding the points of measurement.

4 INSTALLATION METHODS

4.1 Mounting Methods for Accelerometers

4.1.1 Adhesive Mounting

The simplest method of accelerometer mounting is by sticking it to the object with the help of double sided adhesive disk or bees wax. Due to softening of the adhesive the contact of accelerometer with the object may be detached and also the adhesive method of mounting needs smooth, clean, oil-free surface of the object which may not always be available.

4.1.2 Mounting Threads

The securemost mounting is possible by threading the accelerometer to the test object. The accelerometer

manufacturers always provide them with a threaded hole at the base and accessories such as mounting studs or mounting magnets with matching threaded protrusions at the top. For installations on metallic object mounting with the help of magnets would suffice. The vibrations in two (X, Y) or three directions (X, Y, Z) at point are to be measured either with a three directional accelerometer or by threading three unidirectional accelerometers on a mild steel cube welded to the part.

For measurements on concrete parts a mild steel piece with threaded hole is grouted into the concrete with the help of foundation bolts and the accelerometers are mounted by means of studs. Figure 4 shows mounting methods for accelerometers.

4.1.3 Water-Proofing of a Mounting

In case the point selected is underwater or is likely to be subjected to splashes of water, the accelerometer mounting needs to be made waterproof with a waterproof housing onto it, through which the connecting cables are taken out. Figure 5 shows a recommended arrangement for the purpose.

4.2 Equipment Locations and Cable Layouts

The signal conditioner/amplifier, signal processor, plotter/printer should be kept in an enclosed shade having mains power connections, from which cables should be laid up to the measurement point. The laying out cable plays an important part in the accelerometer mountings as cable whips contribute

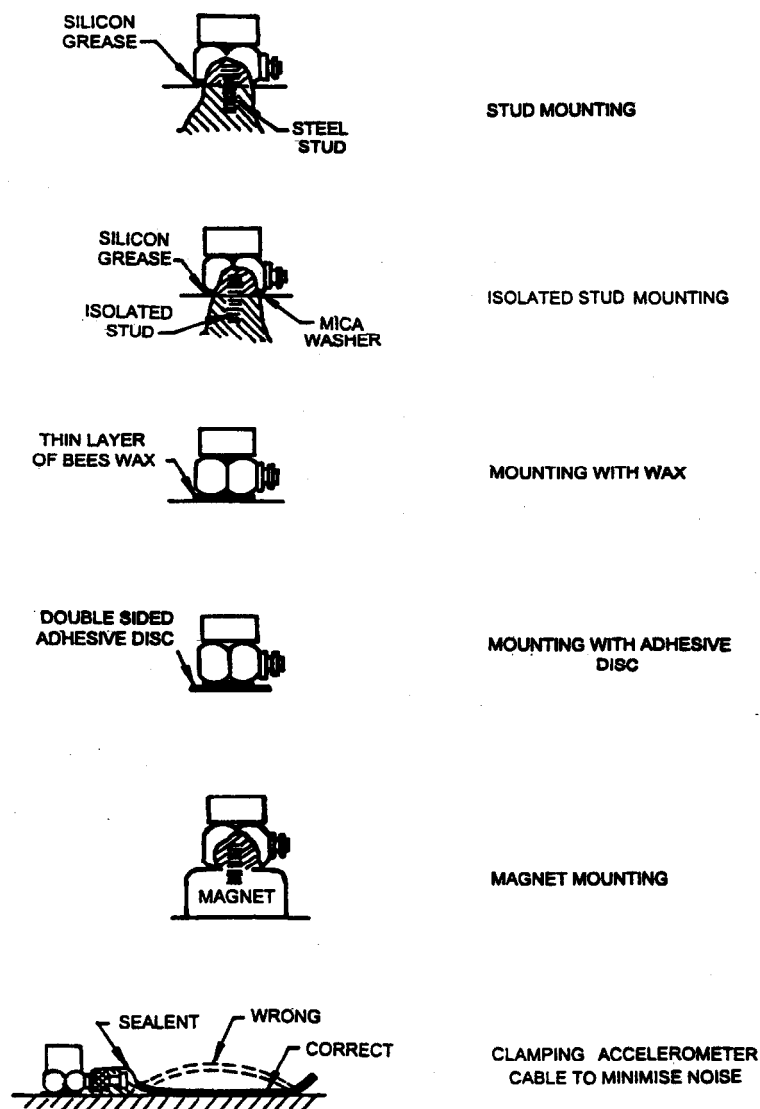


FIG. 4 METHODS OF ACCELEROMETER INSTALLATION

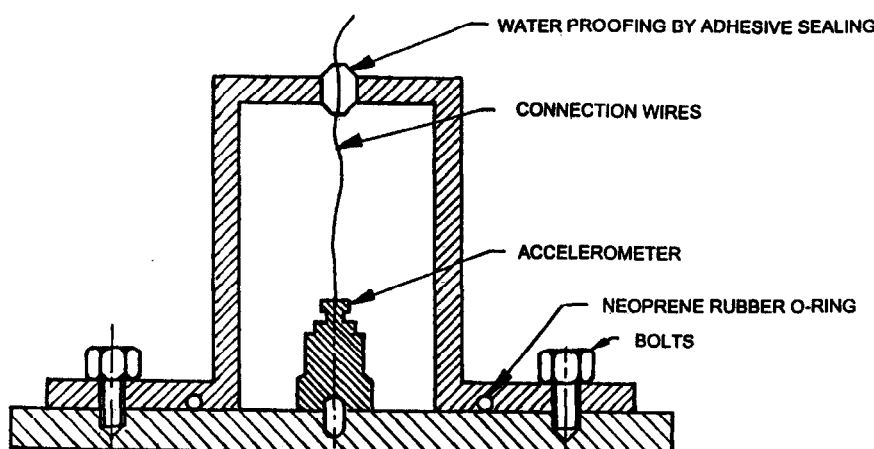


FIG. 5 WATER PROOF HOUSING FOR ACCELEROMETER

to error in measurements arising from introduction of unwanted electrical inputs into the signal conditioning amplifier. The connecting cable should therefore be kept attached to the test objects end, and as far as possible not let free so that whipping due to wind should be avoided, as shown in Fig. 4.

5 EXPERIMENTAL DATA COLLECTION

5.1 Pre-measurement Calibration

The accelerometer and amplifier performance characteristics are generally stable. These, however, should be checked even on site. This should be carried out by reciprocity method for accelerometer using a standard accelerometer, miniature vibration source and sensitivity comparator, and for charge amplifier by charge simulation method using a calibrator producing known charge and a digital voltmeter.

5.2 Instrument Check-Up

Having completed the installation of accelerometers and having made electrical connections of the equipment before data collection, a thorough instrument check is very essential. Considering the sources of vibrations, these would be repetitive in nature and signal validity checks could be easily carried out during this phase. The following require special attention:

- To ensure that the mains supply frequency (50 Hz pick-up, DC off-set and low frequency variations should be minimum possible to an extent that does not affect measurement results.
- The sensitivity ranges should be selected to accommodate the signal within dynamic range of the instruments.

Figure 6 shows instrument set-up for vibration measurements.

5.3 Measurement Procedures

5.3.1 Measurement Conditions

The vibrations change according to various conditions to which the test part is subjected, for example gate openings, electrical load on machine. For each different condition the signal validity may be checked as mentioned in 5.2 for the procedure for instrument check-up.

5.3.2 Measurement Time

A portable signal processor conducts on-line analysis. However, the record time selection should be limited. The frequency range, the frequency resolution and record length are interrelated as follows:

$$T = 1/f_R$$

where T = record time,
 f_R = frequency resolution

$$= (2.56 \times F_{\text{Max}}) / N_t,$$

where

F_{Max} = maximum anticipated frequency of vibrations

N_t = samples in time

5.3.3 Recording Observations

The records of the measurements conducted should be kept in a tabular form. The table should bear at the head all the pertinent details for example, reservoir level, condition of gates, machine speed, head on machines, load, etc, and date and time of experiment. In case of simultaneous measurements on a number of channels, all the locations form the columns and measurement conditions form the rows. Many sub-conditions within a condition are possible for example, a load on hydro-turbine with other unit at different

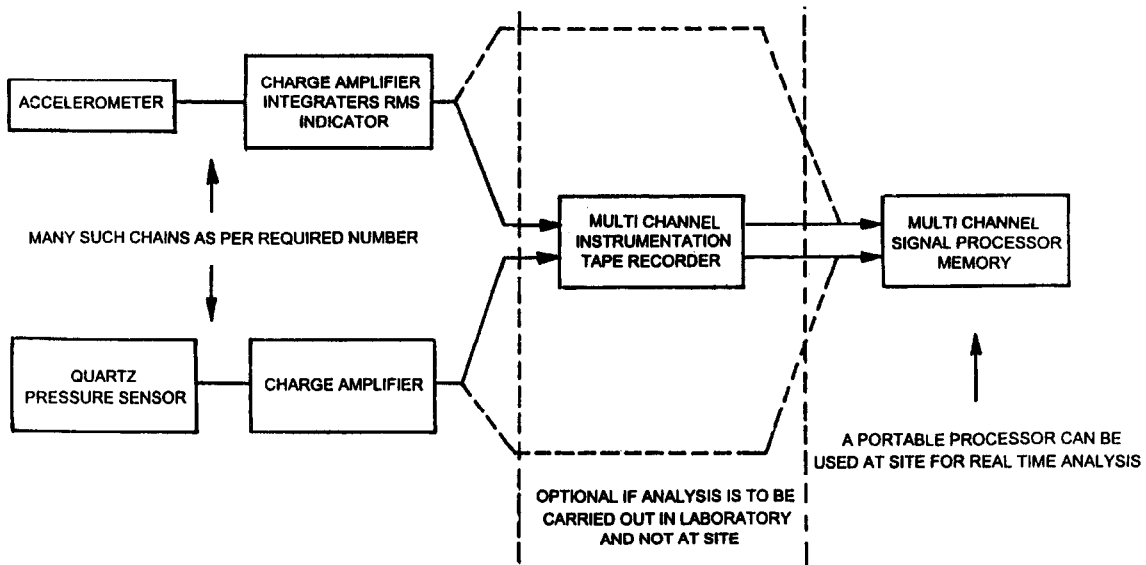


FIG. 6 INSTRUMENT SET-UP FOR VIBRATION AND PRESSURE PULSATION MEASUREMENTS

load conditions.

It is possible that the readings are not taken simultaneously or in the order indicated by this table due to operational constraints or equipment limitations, therefore each condition and sub-condition as well as the points of measurements may be dated and time marked.

Entries should be made in this record during observations for,

- a) actual parameters value while using indicating instrument, and
- b) file names, diskette identification numbers while using signal processor.

Figure 7 shows a typical record of observations

NAME OF PROJECT :
 DATE :
 RESERVOIR LEVEL :
 TAIL RACE LEVEL :
 UNIT NO. :
 GATE OPENING :
 MACHINE SPEED :

MEASUREMENTS POWER GENERATION	TURBINE GUIDE BEARING: VERTICAL	TURBINE GUIDE BEARING: HORIZONTAL	GENERATOR FLOOR BEARING: VERTICAL	GENERATOR THRUST BEARING: HORIZONTAL	CONTROL ROOM FLOOR: VERTICAL	CONTROL ROOM FLOOR: HORIZONTAL
	0 MW					
10 MW						
20 MW						
30 MW						
40 MW						
50 MW						

FIG. 7 A TYPICAL VIBRATION MEASUREMENT RECORD

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Review of Indian Standards

Amendments are issued to standards as the need arises on the basis of comments. Standards are also reviewed periodically; a standard along with amendments is reaffirmed when such review indicates that no changes are needed; if the review indicates that changes are needed, it is taken up for revision. Users of Indian Standards should ascertain that they are in possession of the latest amendments or edition by referring to the latest issue of 'BIS Handbook' and 'Standards : Monthly Additions'.

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