DIGITAL INSTRUMENT RESPONSE CORRECTION METHOD FOR FORCE-BALANCE ACCELEROMETER

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ABSTRACT :

The analysis of instrument response errors for force-balance accelerometer of digital accelerograph system is carried through in this paper, a method for correcting instrument response errors has been put forward (the differential-differential method) , i.e. the un-correction acceleration data are treated by low-pass filtering, they are differentiated twice with approximate ideal differentiators to obtain the corrected accelerogram. In allusion to the earthquake instrument system (KIS) of Daya bay nuclear power station, the instrument response correction demonstration is given, and the corresponding compute processing software are compiled. The method is applicable for instrument response correction processing of accelerogram recorded by digital accelerograph of China strong motion network.

KEYWORDS: Digital accelerograph, Force-balance accelerometer, Instrument response errors correction, Accelerogram, Software

1. INTRODUCTION

In the early 1980s of last century , along with the development of digital observation technique, the digital strong motion accelerograph system has already been used in China strong motion net and mobile observation .There are the accelerometers equipped with this kind of system, such as Type FBA-3 and Type FBA-13 etc. made by American Kinemetrices Company, and Type SLJ-100 researched and made by Institute of Engineering Mechanics, China Earthquake Administration. The digital strong motion accelerograph has many advantageous performances which are not able to be compared by the analog strong motion accelerograph. The records obtained are with big dynamic scope, broad frequency and absolute time scale, and the waveforms are complete with head. But, the digital strong motion accelerograph are generally applied with fore-balance accelerometers, especially for the early force-balance accelerometers with the narrower frequency band scope (from 0 to 30 Hz), and the records for this kind of instruments should carry out the instrument correction.

For the instrument high fregeuncy error correction of the analog strong motion accelerograph, American scholar Trifunac, M.D. etc. researched it, and Chinese scholar Xie Li Li etc. also researched the amperemeter and directly photographic recording accelerometer's analog strong motion accelerograph system. In recent years, Novikova, E.I. and Trifunac,M.D. researched the instrument frequency errors for digital strong motion accelerograph system. In the paper, through the analysis for the force-balance accelerometer instrument response distortion and errors, a processing method for correcting this kind of errors (differential-differential method) has been presented, i.e. after the uncorrected records are Low-pass filtered, the filter is applied with Butterworth, they are differentiated twice by approximately ideal differentiator to obtain the corrected acceleration records. In allusion to the earthquake instrument system (KIS) of Daya bay nuclear power station, a demonstration of the instrument correction has been given, and the computer corresponding processing software have been compiled. The method is suitable for the instrument distortion correction processing for the acceleration records obtained by China strong motion net digital strong motion accelerographs. But, it is necessary to point out that in recent years, the force-balance accelerometers (e.g.FBA-23, SLJ-100 FBA-T) made by U.S.A and China instruments frequency brand scope is usually from 0 to 80 Hz , and both the high frequency and low frequency response characteristics are more superior than the early force-balance

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accelerometers. According to the theory, it is considered that without the instrument frequency response distortion correction processing, it can be satisfied with the frequency scope requirements of the interest to the earthquake engineering.

2. THE ANALYSIS FOR THE INSTRUMENT RESPONSE DISTORTION AND ERRORS

For the working principle of the force–balance accelerometers, it shall not be introduced in detail. The differences among it and other types of sensors lie in that it has an electronic feedback closed loop, and through the feedback closed loop, it can supply wider effective frequency response scope than general sensors, But it is as same as other instruments, has the instrument response errors, i.e. the records can only in the certain frequency segment represent the measured vibration, if beyond this frequency segment, the instrument records will have serious distortion. For FBA-3 Force-balance accelerometer, and near to or beyond the free frequency high frequency vibrating components, the instrument records will include very big errors.
FBA-3 Force-balance accelerometer transfer function measured in the vibration table experiment is shown as Fig1. The results demonstrate: the transfer function curve from 0 to 30 Hz is flat. FBA force-balance accelerator's movement differential equation is as the following:

$$\ddot{X}_n + 2w_n z\dot{X}_n + w_n^2 X_n = -\ddot{X}_g \qquad (1)$$

In the equation:

$$2w_n z = \left(\frac{c}{m} + \frac{DKGg}{mR_0}\right)$$

$$w_n^2 = \left(\frac{K}{m} + \frac{DKG}{mR_0}\right)$$

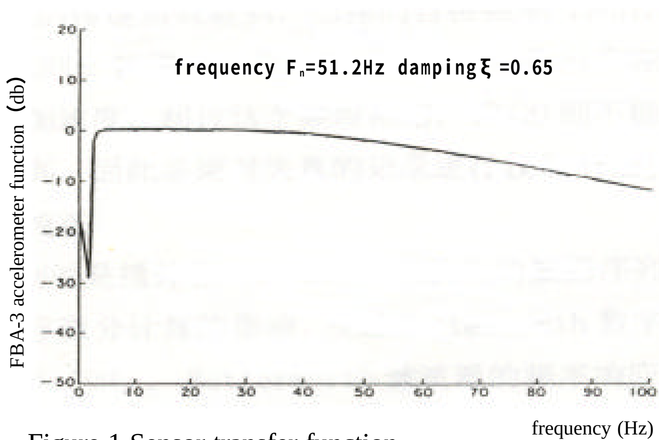

Figure 1 Sensor transfer function

D - variable capacitance modulation factor (volt/meter)
K - feedback closed-Loop gain
G - electric constant (Newton/ampere)
γ - speed conversion relation
Xn represents relative displacement of acceleration sensor vibrating centre, ? is for sensor free frequency, ? is for accelerating sensor damping constant, and Xg is for the measuring point place motion acceleration.
According to the seismograph theory, after introducing the feedback technique, this kind of sensors make the system free frequency increase greatly increase, and the sensitivity doesn't drop, and the system free frequency is greatly bigger than the measured vibrating frequency. The relative displacement for the sensor vibrating centre is directly proportional to the measured ground acceleration, i.e.

$$w_n^2 X_n = \ddot{X}_g \qquad (2)$$

As shown in the transfer function of FBA-3 force-balance accelerometer, when the pendulum free frequency Fm=51.2 Hz, and in the range from 0～30 Hz， the curve is flat. And only in the frequency segment, can it represent precisely the ground movement acceleration. If it is beyond the frequency segment, the sensor movement differential equation cannot be established. At this time the obtained acceleration records may become distorted. So the instrument response correction must be carried out for the distorted records.

3. THE INSTRUMENT DISTORTION CORRECTION METHOD

what the digital strong motion accelerograph system records is sensor pendulum mass relative displacement, and is discretized data series, and written as {Xn}. In order to avoid the noise's effect on the digital differential calculation, Butterworth digital filter should be Low-pass filtered once, the cut-off frequency selected is 50 Hz. Butterworth digital filter frequency response curve is shown in Fig2. The sensor movement differential equation can be changed into:

$$\{\ddot{x}_n\}+2W_n z\{\dot{x}_n\}+w_n^2\{x_n\}=-\{\ddot{X}_n\} \qquad (3)$$

Among them, $\{\ddot{X}_n\}$ is ground movement acceleration $\ddot{X}_g$'s discoretized expression form.

The distortion records (equation2) are differentiated twice, and then the pendulum mass relative velocity $\{\dot{x}_n\}$ and relative acceleration $\{\ddot{x}_n\}$ can be obtained, and according to the above equation, after the combination, at once the records after the instrument response distortion correction can obtain.

In order to reserve many effective high frequency elements in the signals better, we select the approximately ideal differential conversion algorithm, and apply the operation formula

$$\dot{X}_n=\sum_{k=1}^{\infty} b_k\left(X_{n+k}-X_{n-k}\right) \qquad (4)$$

In the actual differential operation, it can use Limited sum to substitute the above equation

$$\dot{X}_n=\sum_{k=1}^{N} C_k\left(X_{n+k}-X_{n-k}\right)$$

By applying the formula, doing faltung integral operation to obtain first-order differential

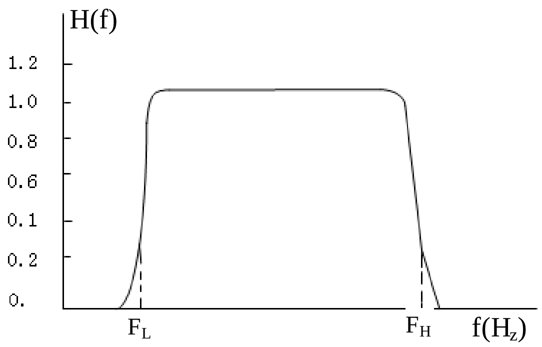

Figure 2 Frequency response curve of Butterworth digital filter

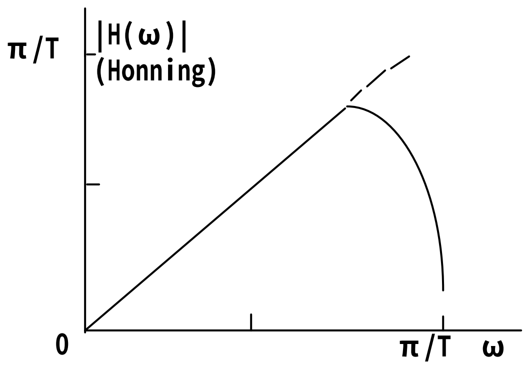

Figure 3 Approximately ideal differential operation transfer function

Similarly, substituting $\dot{X}_n$ into the above equation, after that, through adjustment, obtaining second- order differential $\ddot{X}_n$.

In the equation:

$$C_k=b_k W_k$$

$$b_k=\frac{(-1)^{k-1}}{K\cdot\Delta T}$$

$$W_k=\frac{1}{2}\left[1+\cos\left(\frac{kp}{N}\right)\right] \quad k=1,2,\cdots\cdots,N$$

In order to eliminate Gibbs phenomenon produced because of cut-off Fourier series, we introduce window function wk to make smooth, here Honning window is used.

When getting N=0, the differential operation is carried out, then according to the sensor movement differential equation which has been changed, the corrected acceleration records are obtained. The above given instrument correction method is called as differential- differential method. Fig.3 is approximately ideal differential operation transfer function, and Fig.4 is digital strong motion accelerograph distortion correction block diagram.

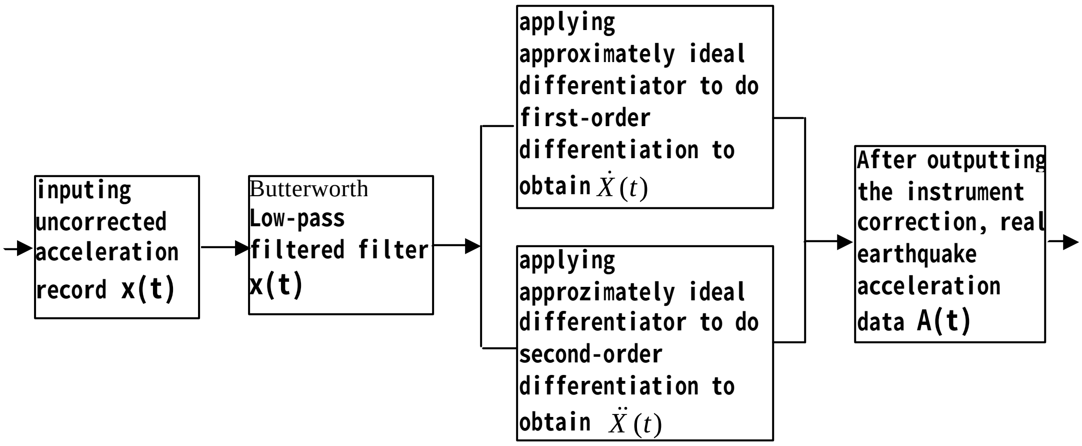

Figure 4 Digital strong motion accelerograph distortion correction block diagram

4. THE DEMONSTRATION OF THE INSTRUMENT CORRECTION

By means of MS Fortran advanced design language, in allusion to the instrument correction method presented, in the paper, the calculation programs have been compiled, and it is applied in Daya bay nuclear power station earthquake instrument system (KIS) standard data processing software.
Type FBA-3 force-balance accelerometer made by American Kinemetrics company is applied for KIS system accelerometer. Because of that since the system was established, it didn't obtain the earthquake records, so the artificial simulation earthquake method is applied for obtaining the artificial simulation earthquake records.
Fig.5 is the artificial simulation record time-histories which is that by means of the instrument correction method presented in the paper, before and after performing the instrument distortion correction calculation for a measured point artificial simulation earthquake acceleration records of KIS system. a, v, and d represent respectively uncorrected acceleration, integral speed, and displacement time-histories. And A, V,and D represent respectively corrected acceleration, integral speed and displacement time-histories.

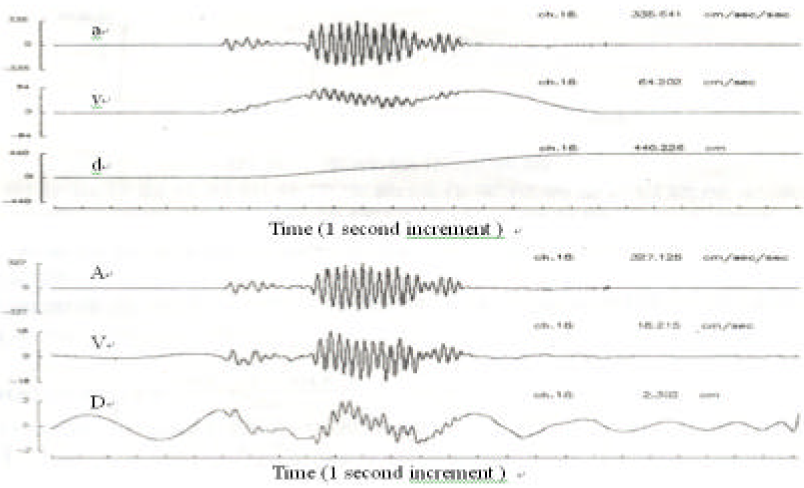

Figure 5 The artificial simulation record time-histories before and after the instrument distortion correction

5. CONCLUSION

The results demonstrate that by means of the instrument correction method presented in the paper, the acceleration time-histories frequency response range for instrument correction processing has been expanded, and the frequency segment is from 0 to 50 Hz, and in the frequency segment, the acceleration records are without high frequency distortion phenomena. Therefore it satisfies the frequency range requirements for the earthquake engineering with great interest. The method is suitable for the acceleration records obtained by China strong motion net digital strong motion accelerograph distortion correction processing. But it is necessary to point out that, in the recent years, the force-balance accelerometers made by U.S.A. and China may not do the instrument frequency response distortion correction processing.

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