A Simple Estimation Method for Impact Location of Loose Parts

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1. Introduction

LPMS (Loose Part Monitoring System) monitors the existence of a loosened or detached metal object inside the pressure boundary of NSSS and identifies, if any, its characteristics such as mass, energy, or impact location. Recently, it is being recognized that LPMS can contribute to improve the plant safety and operational costs in such a way that, at an early stage, it can identify the metal object which has a potential of causing a severe damage to an internal component such as the upper plate of steam generator hot chamber or fuel rods in the reactor core. And also, its importance is being increased though it is not the safety class in nuclear power plants.

Estimation of impact location of a loose part in the pressure boundary has three different methods: triangular method, circle intersection method, and envelope method. The first two methods are based on the delay of arrival times of impact signal into two or three sensors and the last is based on the signal patterns. For the time delay methods, the precise identification of the arrival time at a sensor and the wave velocity is a pre-requirement for estimating accurately the impact location, and this is very difficult to carry out systematically. In this paper, a new and simple algorithm is proposed to identify the arrival time and the wave velocity conveniently by use of so-called Teager's algorithm [1]. This method performs the impact location estimation with a reasonable accuracy.

2. Description of Impact Location Identification

The envelope shape of an oscillating signal can be obtained through some useful method such as Hilbert transform [2]. Teager's algorithm can also estimate the energy shape of a pure oscillating signal. This method has some merits and demerits. One important merit is that this algorithm is very simple and hence, it can be implemented very easily in the analysis software and performed near on –line. Teager's algorithm is expressed as follows.

$$E(n) = x(n)^2 - x(n-1)x(n+1) \quad (1)$$

In Eq.(1), E is the energy of the signal, x is the signal sample, and n the time index. A critical restriction of Teager's algorithm is that it must be operated on a signal whose frequency range is less than one-eighth of the sampling rate. Fig. 1 shows the energy extraction for an impact signal acquired from the calibration test on the steam generator of Uljin NPP Unit 2. The upper graph shows the acquired signal with the sampling rate of 200 kHz. The middle graph is the filtered signal by a band pass filter of 1 ~ 12 kHz, sufficiently lower than the sampling rate, and the lower graph shows the signal energy by Teager's algorithm. As can be seen in Fig.1, the maximum value of signal energy represents the most energetic portion of an impact signal that is a flexural wave produced in the structure by the loose part impact. The arrival time of an impact signal is given by the maximum energy point in the lower graph of Fig.1, i.e., the most dominating point of an impact signal. In fact, as will be presented later, it can be derived that the peak of the energy signal represents the arrival point of a wave with the group velocity.

The group velocity for a flexural wave in the structure like a component of nuclear power plant is dependent on the frequency of an impact signal. The phase (or bending) and group velocities for the components in NPP with one side boundary surrounded by water can be expressed (in the unit of ft/sec) as follows [3].

$$C_b = C_{LI}\sqrt{\frac{1.8hf}{C_{LI}+4.5hf}},\ C_g = \frac{6.72\times10^9 hf}{\sqrt{1.18\times10^{10}C_b^2+3.82\times10^{11}h^2f^2}}, \quad (1)$$

where, C_b is the phase velocity, C_g is the group velocity, C_{LI} is the quasi-longitudinal wave velocity, h is the plate thickness (ft), and f the dominant frequency (Hz). In Eq.(1), the dominant frequency (F_D) is obtained by the Hertz impact theory, i.e., $F_D = 0.8/T_C$,where T_C is the impact contact time.

The impact contact time can be obtained from the time signal by measuring the time interval between two positive-going (or negative-going) excursions or directly from frequency spectrum [4]. The process of measuring the contact time and arrival time must require the manual operation, which contains larger uncertainties. In order to reduce uncertainties and improve the location estimation, time-frequency method was proposed recently [5].

In this paper, a simple and systematic method for measuring the contact time is proposed. Fig.2 shows the normalized energy and filtered impact signals displayed simultaneously. As can be seen in Fig.2, the energy signal envelopes well the impact bending wave. And the time interval between two negative-going excursions in the first impact bending wave is almost same as the duration of the pulse of the energy signal. Thus the dominant frequency is set by the inverse of the duration of the first energy pulse.

3. Experiments

This algorithm was programmed and applied to the impact signals acquired from the laboratory test on the metal plate with the thickness of 20 mm. For the plate whose boundary is free, the phase velocity (C_b) and group velocity (C_g) are expressed as follows: $C_b = (1.8C_{LI}hf)^{0.5}$ and $C_g = 2C_b$. The impact signals were sampled with the rate of 196.5 kHz. These were filtered by a band pass filter with the bandwidth of 1~23 kHz which is much lower than the laboratory-installed sensor resonance frequency (50 kHz) and also satisfies the restriction of the Teager's algorithm. Alternatively, the average C_g can be obtained from a pre-test because of the fact that the peak of the energy signal represents the group velocity. Fig.3 displays the estimation result of impact location. For various impacts by metal balls with 6 types of mass, the estimation results for the impact location are represented in Table 1, where the average estimation error is 40.9 mm (and the average estimation error for a pre-determined constant C_g is 25.9 mm).

4. Conclusion

Systematic identification of the arrival time and the wave velocity is presented in this paper based on the Teager's algorithm. This method shows a reasonably good accuracy in the estimation of impact location and can be easily implemented in the LPMS software that performs the systematic identification of the impact location.

Fig.1 Impact Signal Energy Calculation

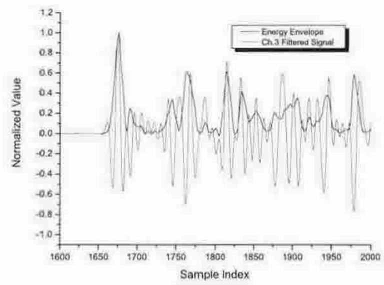

Fig.2 Normalized Impact and Energy Signals

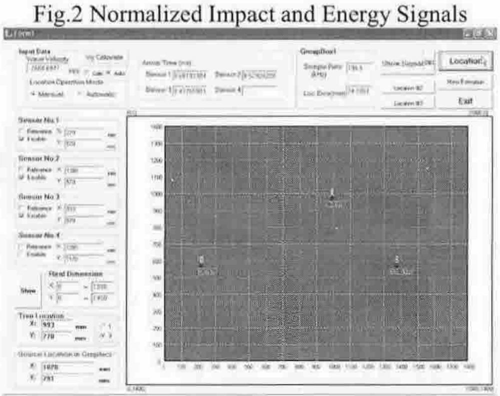

Fig.3 Impact Location Estimation

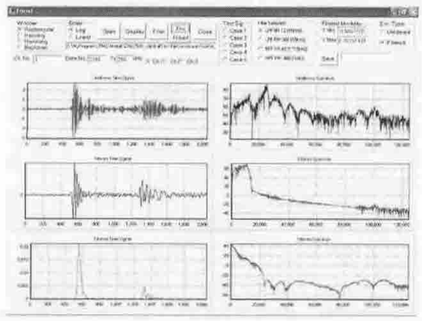

Table 1 Experimental Results

File Name	Mass(g)	True Location (mm)	Estimation (mm)	Deviation (mm)
Pb09h100ch3no1	2.7	(993, 770)	(1020, 791)	34.2
Pb09h100ch3no2	2.7	(993, 770)	(1020, 780)	28.8
Pb09h100ch3no3	2.7	(993, 770)	(1011, 751)	26.2
Pb09h200ch3no1	2.7	(993, 770)	(1005, 748)	25.1
Pb09h200ch3no2	2.7	(993, 770)	(1008, 751)	24.2
Pb09h200ch3no3	2.7	(993, 770)	(1022, 774)	29.3
Pb13h100ch1no1	8.5	(446, 687)	(468, 637)	54.6
Pb13h100ch1no2	8.5	(446, 687)	(460, 634)	54.8
Pb13h100ch1no3	8.5	(446, 687)	(460, 634)	54.8
Pb13h100ch3no1	8.5	(993, 770)	(1025, 794)	40.0
Pb13h100ch3no2	8.5	(993, 770)	(1014, 777)	22.1
Pb13h100ch3no3	8.5	(993, 770)	(1025, 794)	40.0
Pb13h200ch3no1	8.5	(993, 770)	(1025, 785)	35.3
Pb13h200ch3no2	8.5	(993, 770)	(1002, 760)	13.5
Pb13h200ch3no3	8.5	(993, 770)	(1000, 757)	14.7
Pb18h100ch3no1	23.3	(993, 770)	(1017, 785)	28.3
Pb18h100ch3no2	23.3	(993, 770)	(1020, 788)	32.4
Pb18h100ch3no3	23.3	(993, 770)	(1031, 788)	42.0
Pb18h200ch3no1	23.3	(993, 770)	(1022, 782)	31.4
Pb18h200ch3no2	23.3	(993, 770)	(1020, 788)	32.5
Pb18h200ch3no3	23.3	(993, 770)	(1025, 794)	40.0
Pb25h100ch3no1	66.7	(993, 770)	(1020, 774)	27.3
Pb25h100ch3no2	66.7	(993, 770)	(1017, 777)	25.0
Pb25h100ch3no3	66.7	(993, 770)	(1017, 774)	24.3
Pb25h200ch3no1	66.7	(993, 770)	(1017, 768)	24.1
Pb25h200ch3no2	66.7	(993, 770)	(1025, 780)	33.5
Pb25h200ch3no3	66.7	(993, 770)	(1028, 802)	47.4
Pb29h100ch1no1	103.6	(446, 687)	(520, 585)	126.0
Pb29h100ch1no2	103.6	(446, 687)	(520, 577)	132.6
Pb29h100ch1no3	103.6	(446, 687)	(511, 574)	130.4
Pb35h100ch1no1	225.9	(993, 770)	(988, 762)	9.4
Pb35h100ch1no3	225.9	(993, 770)	(1017, 762)	25.3

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