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# A study on the stress history condensation method for a fatigue monitoring system

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## 1. Introduction

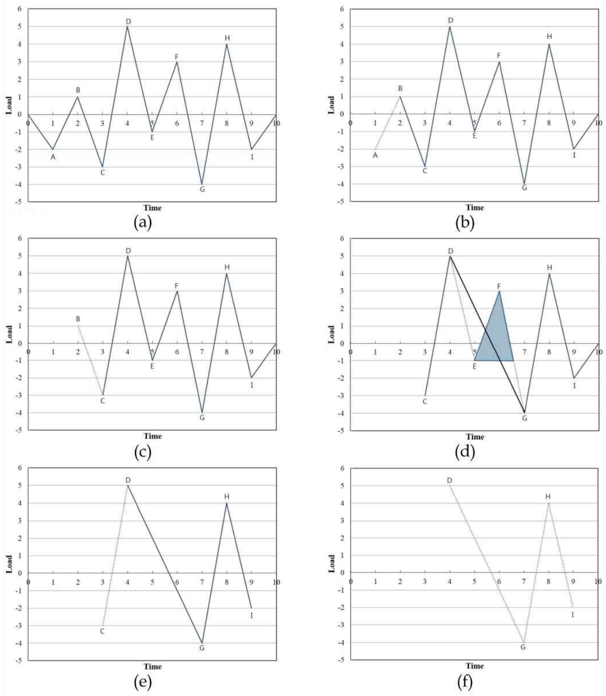
As the lifetime of nuclear power plants (NPPs) reaches their design life, various aging mechanisms occur. NPPs are required to manage the aging effects of SCCs for a period of extended operation. So, many researches are being conducted to assess the feasibility and develop solutions to safely extend NPP lives.

Fatigue damage is the one of important aging mechanisms. Time-varying thermal, pressure and mechanical loads produce perturbations of stress cycles primarily at the surface of a component. Stress cycles of sufficient magnitude cause fatigue damage, which can ultimately lead to cracking of the component. According to NUREG-1801, fatigue monitoring systems identify acceptable aging management programs, including programs for fatigue and cyclic operation [1]. In a monitoring system, the rainflow counting method is mainly used as the stress cycle counting method. Before determining the stress cycles using rainflow counting method, stress extremum (or peak/valley) must be identified. Because real stress history contains large numbers of very small cycles, which may be a result of digitization noise, these cycles will slow down the analysis and distort the scaling of graphical displays [2].

In this paper, an engineering methodology which extracts stress extremum from the stress history, so-called the simple extremum extraction (SEE), is proposed. Depending on the application of the SEE, the stress cycles counted by the rainflow counting method are compared. As a result, it is found that stress cycles smaller than a threshold value are discarded by using the proposed method.

## 2. Rainflow counting method

The rainflow counting method was proposed by Matsuishi and Endo in 1968 to count the number of cycles of each stress range in a stress history. Based on an extensive series of axial strain controlled fatigue tests, Dowling demonstrated that the rainflow counting method accurately identified closed hysteresis loops in a variable amplitude histogram. It was concluded that counting methods other than range-pair and rainflow methods resulted in enormous differences in predicted and actual fatigue lives. To apply the rainflow counting method, a stress history has to be oriented vertically with positive time pointing downward. Then, the fall of rain from top of the stress history is used to facilitate the method. The rainflow paths are defined according to the following rules :



| Range | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Counts | 0 | 0 | 0.5 | 1.5 | 0 | 0.5 | 0 | 1.0 | 0.5 | 0 |
| Event | | | A-B | B-C<br>E-F | | H-I | | C-D<br>G-H | D-G | |

Fig. 1. The schematic of a rainflow counting method

a) A rainflow path is started at each peak and valley.

b) When a rainflow path that started at a valley comes to the tip of a roof, the flow stops if the opposite valley is more negative than that at the start of the path under consideration. Conversely, a path that started at a peak is stopped by a peak which is more positive than that at the start of the rain path under consideration.

c) If the rain flowing down a roof intercepts flow from previous path the present path is stopped.

d) A path is not started until the path under consideration is stopped.

Fig. 1 illustrates an example of rainflow counting method.

## 3. Simple extremum extraction

The objective of SEE is to condense and reveal significant peak and valley in a complex stress history. The procedure in the Fig. 2 shows the core algorithm of SEE. First of all, it is confirmed whether the input value is local peak or local valley (the 1st and 2nd decision point in Fig. 2). And, then the input value is extracted as the reversal peak / valley if the difference between the input value and local peak / valley is larger than the

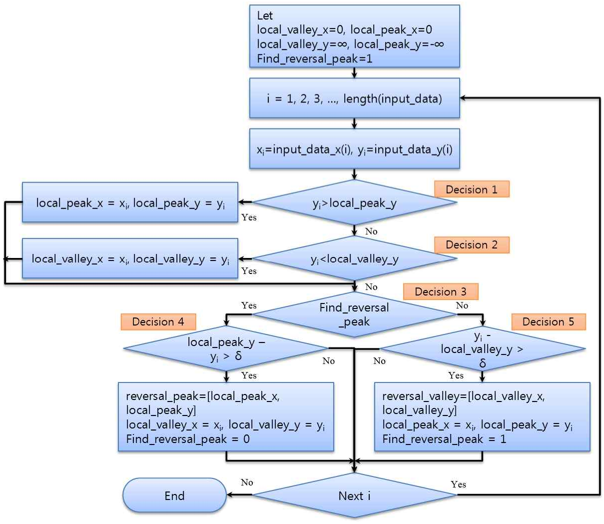



Fig. 2 The algorithm of the simple extremum extraction

specific threshold (the 4th and 5th decision point in Fig. 2). As shown in Fig. 2, the calculation is very simple because only the difference between the input value and local peak / valley is used in order to check whether the input value is the extremum. Any slopes of the stress or absolute difference values are not used. So, the execution speed of this algorithm is very fast.

## 4. An analysis of the random stress history

To verify the proposed method, the stress cycles counted by rainflow counting method and SEE are compared with those counted by only rainflow counting method. Fig. 3 shows an example of a normalized stress transient. The stress cycles on this transient are determined by using rainflow counting method and SEE. The applied threshold value is 2.

Fig. 4 shows the new transient condensed by SEE. Stress values at 5, 12, 13 and 14 sec. are extracted as extremum. And, the condensed transient as dotted line in the Fig. 4 is composed by using the extracted extremum. Table 1 represents the stress cycles counted by two method and Table 2 shows the stress cycles counted by only rainflow counting method. As the analysis results, it is found that stress cycles smaller than a threshold value are eliminated. As the application of the SEE, the original complex transient is condensed to a smoother transient, and small amplitude cycles causing negligible fatigue damage are discarded.

Table 1 The stress cycles counted by the rainflow counting method and SEE

| Stress Amplitude | 1 | 2 | 4 | 6 |
|---|---|---|---|---|
| Number of Cycles | - | 1.5 | 0.5 | 0.5 |

Table 2 The stress cycles counted by the rainflow counting method only

| Stress Amplitude | 1 | 2 | 4 | 6 |
|---|---|---|---|---|
| Number of Cycles | 5 | 1.5 | 0.5 | 0.5 |

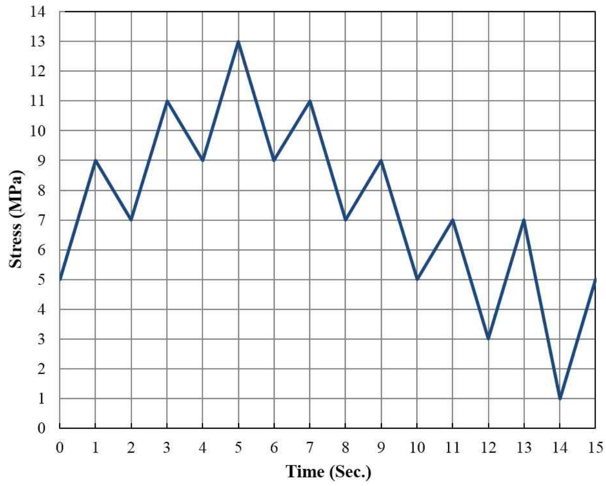



Fig. 3. The normalized stress transient

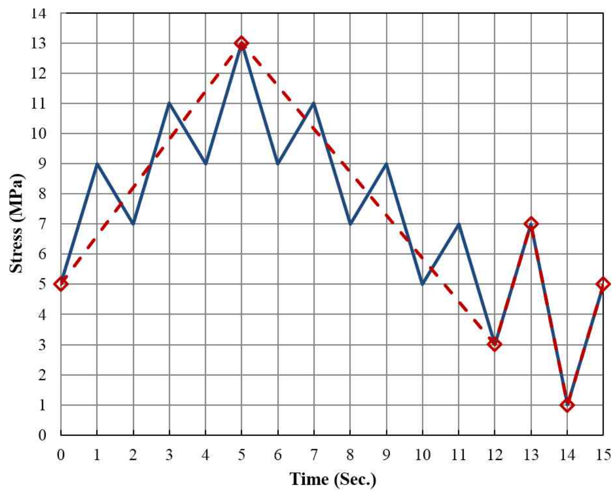



Fig. 4. The comparison between the original transient and the condensed transient

## 5. Conclusions

In this paper, an engineering methodology which extracts extremum from the real-time transient data, so-called SEE, has been developed. The proposed method is very simple and so fast because it only uses the difference between the input value and local peak/valley. The stress cycles counted by two methods are compared with those counted by only rainflow counting method and it is found that stress cycles smaller than a threshold value were eliminated. As the application of the SEE, the original complex transient is condensed to a smoother transient, and small amplitude cycles causing negligible fatigue damage are discarded.

## REFERENCES

[1] USNRC, "Generic Aging Lessons Learned (GALL) Report," NUREG-1801, 2005
[2] Carney, C., Gilman, T., "Stress-based fatigue monitoring, Methodology for fatigue monitoring of class 1 nuclear components in a reactor water environment," EPRI Technical report, 2011