Fatigue Life Estimation of Elevator Car Frame with Double Floor by Stress Time History Simulation

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Abstract

The elevator car is an important load-carrying unit of the elevator, so any damage of car parts can cause unsafety for the user, especially for the passenger elevator. To eliminate the risks of insufficient strength, each elevator is inspected and tested with a load equal to 125% of its nominal load before being put into service. However, load testing in-situ can only detect damage related to the static strength, the fatigue hazards are difficult to be detected because fatigue accumulation occurs very slowly and depending on the stress time history. In practice, elevator structural elements are usually calculated in terms of its static strength, with a factor of safety taken higher than those of other structures without regard to fatigue strength. This paper presents the research results related to the calculation of fatigue life of the elevator car frame through simulated stress time history by numerical method. Our method shows that the fatigue life of the elevator car frame can be predicted in the design stage.

Keywords: Elevator car, stress time history, fatigue life

1. Introduction

The elevator car is a common load-carrying component for the passenger elevator. It comprises main frame (parts 1, 2, and 3), steady floor (4) and movable floor (5), walls, and roof as shown in Fig. 1. The double floor structure (steady and movable) can improve the performance of the elevator and makes overload control easily. The load on the floor and the mass of components transfer to the main frame via four rubber supports (6), placed between the movable and steady floors. The position and distribution of the load acting on the floor depend on the way of loading. For a passenger elevator, the load on the floor is defined by the mass and number of passengers and their positions. The mass of each person is given by the standard, for example, 75 kg by EN81-20 standard. Naturally, people enter the car and stand where they want. So the load on the floor is random, and it is valid not only for the value (number of passengers) but also for the position of the acting point. These random loadings on the car floor lead to the fluctuating of the stress in the elements of the structure and further to the risk of fatigue damage of those elements.

Recently, the car frame is calculated only based on the static strength of the elements, not dealing with the problem of fatigue damage. The standards [1-3] specify the safety requirements for the construction, installation, and use of an elevator and only a few formulae for approximately designing of some elements of the elevator. Another research focused mainly on the problem of static calculation, using the nominal load in the car as concentrated force acted eccentrically on the single floor or equally distributed on the safety plank [4-7]. The papers [8, 9] introduce the double floor structure of the elevator car and deals with the stress/deformation behavior of the elevator frame under different load cases, but no mention of fatigue damage yet.

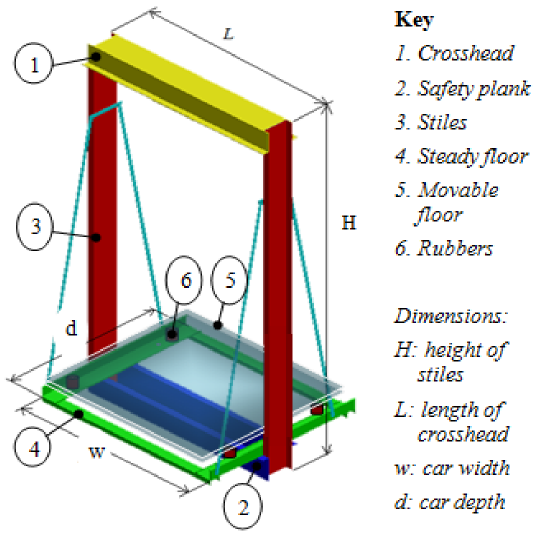

Fig. 1. Car frame structure

The goal of this research is to diagnose the fatigue life of the car frame structure at the design stage. Clearly, for the calculation of fatigue life, the

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stress time history is needed. However, at design stage, the car does not exist yet, so the stress time history can only be obtained from the numerical method. For this purpose, the work process of the elevator car is considered as the following.

The working cycle of the elevator consists of successive tasks:

- loading;
- starting of the machine, car runs up or down;
- stopping of the machine, car stops;
- unloading.

For a passenger elevator, when stopped at the landing to catch passengers, the car is not always empty, but sometimes there are already loads. So load on the floor may be divided into two phases: before loading and after loading to unloading tasks. Because of these characteristics, the peak stresses in the structure are calculated respectively by these loads for every working cycle.

2. Stress time history simulation

As mentioned before, there are two kinds of loads acted on the car frame. The mass of car components is considered constant, and the mass of passengers on the car floor is a random one. All these masses are transferred to the car frame by four rubber supports as shown in Fig.2. The stress in the car frame is calculated from these loads by analytical or finite element methods (FEM). Because of the randomness of the number of passengers and their positions on the floor, the number of loading cases is very large. For example, an elevator has a nominal load of 10 persons but on the floor may stand 0 to 12 persons at the same time and the passenger positions are approximately distributed as shown in Fig.2 (solid circles). If each position is marked as a bit ("0" for the position without passenger, "1" for the position with passenger) then the load cases vary from 000000000000 (empty car) to 111111111111 (full loaded), and the total number of combinations (load cases) is very large. The case shown in Fig.2 is referred to 000010000010.

The result of calculating by FEM method shows that the maximal value of Von-Mises stress occurs at the middle section of the crosshead (Fig.3) and this stress does not comply with the superposition rule, but its normal and tangential portions do, i.e. the total normal (or tangential) stress can obtain by adding the stresses, calculated separately from each load. For this result, the simulation of stress time history can be performed using the following procedure:

a) Pre-calculation:

+ Calculate normal and tangential stress for an empty car (constant load);

+ Calculate normal and tangential stress for load 75 kg at each position in Fig.2.

b) Stress time history generating, using the Monte-Carlo method to simulate the number and position of passengers:

+ Generate the number of passenger on the floor by given statistical rule;

+ Generate the position of the passenger; two passengers cannot stand at the same position;

+ Sum of the stresses, separately normal and tangential portions;

+ Calculate Von-Mises stress;

+ Record the extreme values.

c) Repeat step (b) for the next working cycle to build stress time history.

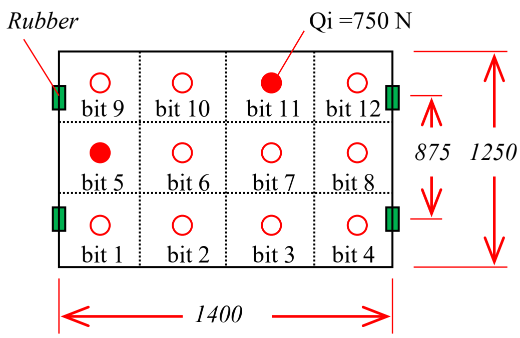

Fig. 2. Loading on the car floor

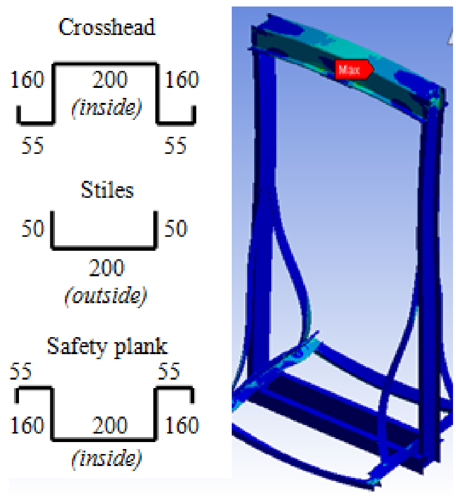

Fig. 3. Car frame members and stress distribution

The example of the simulated stress time history is shown in Fig. 4 (drawn only extreme values).

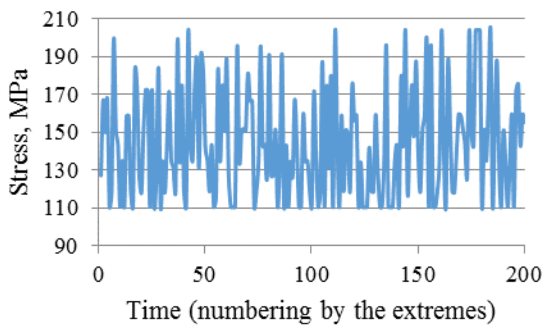

Fig. 4. A portion of simulated stress time history

3. Fatigue life estimation

From the stress time history, the stress ranges needed for fatigue estimation can be extracted by a stress counting procedure. In this paper, the "Rain Flow" (RF) method is used for this purpose. Further, the counted stress ranges can be used to estimate the fatigue life by the fatigue damage cumulative criterion. Some of these criteria are shown in Fig.5.

One of the most commonly used is the criterion of Palmgren-Miner when the minor stress ranges are ignored. By this criterion, the fatigue damage will occur when:

$$D = \sum_{\sigma_i \geq \sigma_{-1k}} \frac{n_i}{N_i} = 1 \tag{1}$$

where,

D is cumulative damage, calculated for the stresses with an amplitude larger than fatigue limit σ_{-1k};

σ_i = stress amplitude, equal to half of the stress range;

σ_{-1k} = fatigue limit, depending on the material and stress concentration effect:

$$\sigma_{-1k} = \frac{\sigma_{-1}}{k} \tag{2}$$

σ_{-1} = fatigue limit the stress of the material, defined by the fatigue test of the samples without stress concentration effect;

k = factor of stress concentration;

n_i = number of stress cycles with amplitude σ_i;

N_i = fatigue life of element when loaded with stress amplitude σ_i, defined by S-N equation:

$\sigma_i^m N_i = \sigma_{-1k}^m N_0$, or

$$N_i = N_0 \left(\frac{\sigma_{-1k}}{\sigma_i} \right)^m \tag{3}$$

In this equation, *m* and N_0 are the characteristics of the S-N curve. For welded steel structure usually $m = 3$ and $N_0 = 2 \times 10^6$ cycles.

Fatigue life, expressed in working cycles of the elevator, L_f, can estimate from equation (1) by the equation:

$$L_f = \frac{s_i}{D} \tag{4}$$

where s_i is the number of working cycle (engine starts), simulated for calculating cumulative value *D*.

By the criterion of Haibach-Gnilke, taking account of smaller stress ranges, the fatigue damage will occur when:

$$D = \sum_{\sigma_i \geq \sigma_{-1k}} \frac{n_i}{N_i} + \sum_{\sigma_{-1k} > \sigma_j \geq \sigma_{HG}} \frac{n_j}{N_j} = 1 \tag{5}$$

Fatigue life for minor stress ranges N_j can obtain by equation (3), but the values of *m*, N_0 and σ_{-1k} are replaced respectively with:

$$\begin{cases} m_{HG} = 2m - 1 \\ N_{HG} = 10^8 \\ \sigma_{HG} = \sigma_{-1k} \left(\frac{N_0}{N_{HG}} \right)^{1/m_{HG}} \end{cases} \tag{6}$$

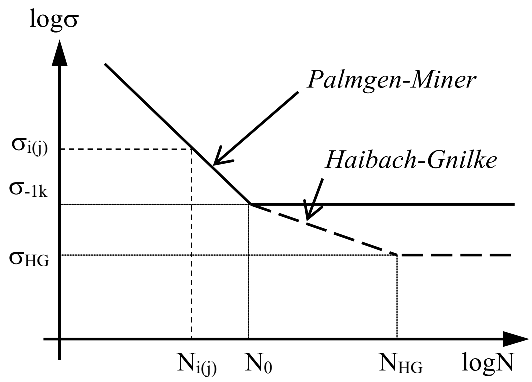

Fig. 5. S-N curves and cumulative criteria

4. Result and discussion

The main parameters of the car being examined are shown in Table 1.

Table 1. Car general parameters

Capacity	10 persons (750kg)
Mass of unloading car	1000kg
Floor area	1250mm width x 1400mm depth
Car frame parameters	Sections of members: as in Fig.3 Material: SS400 sheet, 4 mm thickness

Table 2. Variation of the calculated fatigue life

Number of simulation cycles	Mean of fatigue life and maximal deviation from the average value			
	by Palmgen-Miner		by Haibach-Gnilke	
	10^6 starts	%	10^6 starts	%
500	12.2	11.03	8.2	8.48
1000	11.5	9.66	8.2	3.93
1500	11.5	6.25	8.2	5.93
2000	11.3	5.64	8.0	4.76
2500	11.6	3.46	8.1	2.98
3000	11.4	**2.63**	8.0	**2.27**

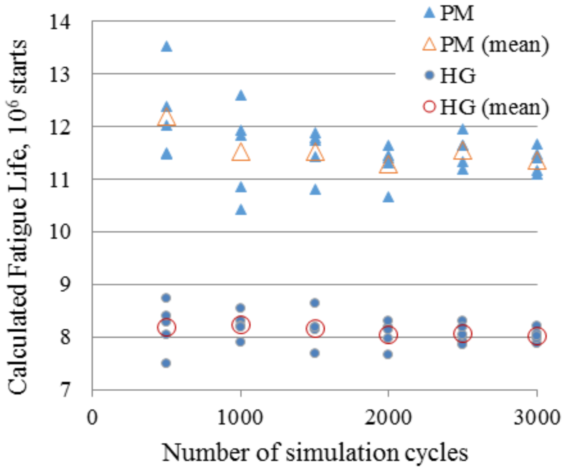

Fig. 6. Calculated fatigue life

Because of the random nature of simulated stress history, the calculated fatigue life varies. To determine the varying range of the results, for each given number of engine starts are simulated five sets of stress history and make fatigue life calculation for each set respectively. The results are shown in Fig.6.

The results show that when the number of starts increases then the variation of calculated fatigue life decreases, so the results are expected to converge. When the number of starts is equal to 1500 (3000 working cycles) the calculated fatigue life varies less than 3% from the average level (Table 2), and this average value of calculated fatigue life can be accepted as the final result.

The calculated fatigue life depends on the used criterion, the Palmgen-Miner criterion gives longer life than Haibach-Gnilke one, and using the Haibach-Gnilke criterion will give more safety when doing the estimation of fatigue life.

The lifetime expressed in years depends on the intensity of work. For example, if the elevator engine starts 30 times per hour for 12 hours per day, and 350 days per year, the lifetime by Haibach – Gnilke is approximately 63 years.

This value is so large, but for old or more intensive used elevators, the unsafe hazard will occur due to fatigue damage and this fact must be taken into account when design, installation, inspection, and use of these elevators.

5. Conclusion

The loading/unloading in and out of an elevator car is a complex process with random nature, repeated many times in the elevator life. Because of this, the stress occurred in the car frame varies and can cause fatigue damage to the structure members of car frame, which leads to unsafe use of the elevator.

The fatigue damage occurs only after a certain amount of time since the elevator is installed and it cannot be detected easily in normal inspection tasks, so the elimination of the risk for this kind of damage is difficult. The method given in this paper can be used for diagnosing the fatigue life of car frame or other elevator structural members even at the design stage.

The calculated results can also provide helpful recommendations to competent persons for evaluation when repairing, modernizing, or replacing the existing elevator.

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