Prediction of Room Noise Caused by Vibration of High Power Elevator Traction Machine

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Abstract—Total simulation from vibration of elevator motor to noise at sitting room with anti-vibration measures is confirmed in design stage. This procedure also presents decrease of acoustic noise in sitting room. In this simulation, FEM calculates wave motion, such as wave phase, interference, diffraction and natural frequency mode of sitting room wall. These procedures yield the ration between vibration of elevator motor and acoustic noise in sitting-room.

Keywords—elevator motor;accoustic room noise; vibration

Received: May 20, 2019. Revised: October 5, 2021. Accepted: October 19, 2021. Published: November 14, 2021.

1. Introduction

Elevators are major means of transportation installed in various facilities from skyscrapers to low-rise buildings to assist us in our daily lives. In some cases, however, elevators may cause a problem in that vibrations from the elevator traction machine propagate to a l iving space near the machine room, generating vibrations and noise in the living space. What is worse, an increase in magnetic flux density resulting from the recent trend towards more compact designs and a decrease in structural rigidity resulting from the recent trend towards lightweight designs are contributing to higher energy per unit volume electromagnetic vibrations generated by the traction machine. About vibrations from a high-power traction machine, e electromagnetic force mode and vibration mode during g operation have not been clarified sufficiently. Thus, if the vibrations of a high-power traction machine can be estimated by simulation, measures can be taken at the vibration source propagation path, and noise emission location to effective reduce the vibrations.

This simulation used Finite Element Method, which can calculate any type of room shape. FEM models the form by y meshed plane. Finite Difference method has some difficulty in collaboration with vibration and acoustic noise. In Boundary Element Method, it is hard to simulate propagation of vibration from traction machine to the room.

Hitherto, estimation of acoustic noise inside of car has done, but simulation of room of building by FEM has no papers.

In this paper, we (1) predicted a vibration response from structure-electromagnetic analysis, (2) found that the vibration mode during elevator operation depends not on the electromagnetic force mode but on the structural natural vibration mode, and (3) identified the location at which vibrations can be prevented from transmitting to the motor leg by discovering that the vibration mode during operation is not a rotation vibration mode but a standing wave mode having fixed vibration nodes. The verification process, analysis, experiments, and finite element method (FEM) analysis will be described.

2. Analysis Procedure

2.1 Procedure

Finite Element model of the traction machine, 200kW motor, is shown in Fig.1. In this figure, traction machine,

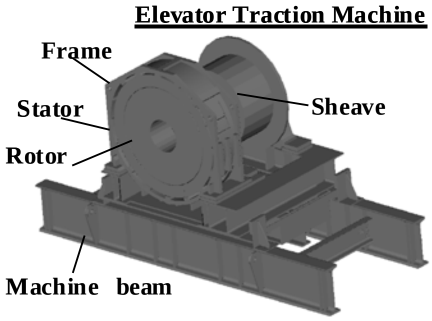

Fig.1 Three dimensional FEM model

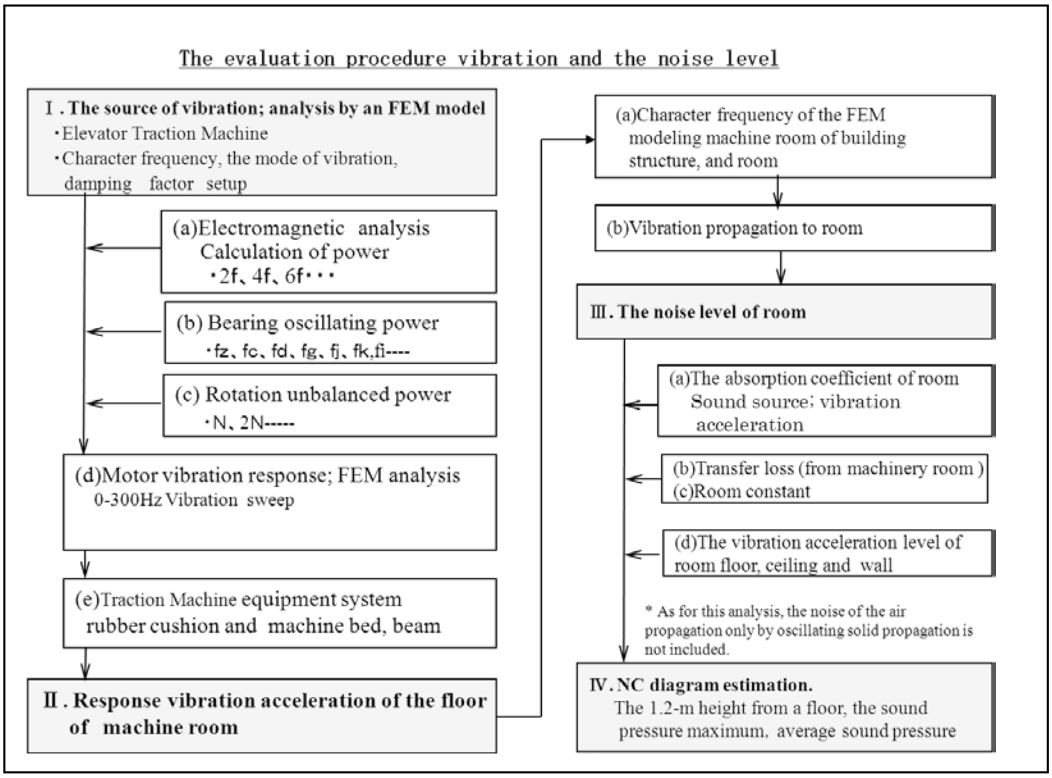

Fig.2 Procedure of FEM analysis

motor, frame of the motor, sheave, motor rotor and machine beam are modeling.

Analysis procedure of the FEM simulation is shown in Fig.2. In Fig.2, Step I provides vibration forces such as electromagnetic forces, bearing vibration forces and rotational unbalanced forces.

Step Ⅱ, building is modeled by three dimensions and its natural frequency is calculated.

Step Ⅲ, room noise is calculated by FEM, considering wave motion of the noise. Step Ⅲ, maximum and average sound pressure are simulated.

As shown in Fig.3, electromagnetic forces are produced by interaction of air-gap harmonic fluxes. These forces vibrate the stator and the rotor. These vibrations yield acoustic noise of the traction motor. Electromagnetic FEM calculate air-gap flux distribution and electromagnetic forces.

These electromagnetic forces are de-composited each frequency's components. Frequency's component is the applied force in mechanical FEM. Logarithm damping factor δ is 1.0percent from the experiments. This value affects vibration response of the traction motor.

This procedure is the combined use of electromagnetic FEM and mechanical FEM [1]-. [4].

2.2 Electromagnetic force analysis

Electromagnetic forces are produced by harmonic fluxes of the stator and the rotor of the harmonic fluxes of the motor, that is traction machine. Combination of these fluxes provides electromagnetic forces in the air-gap.

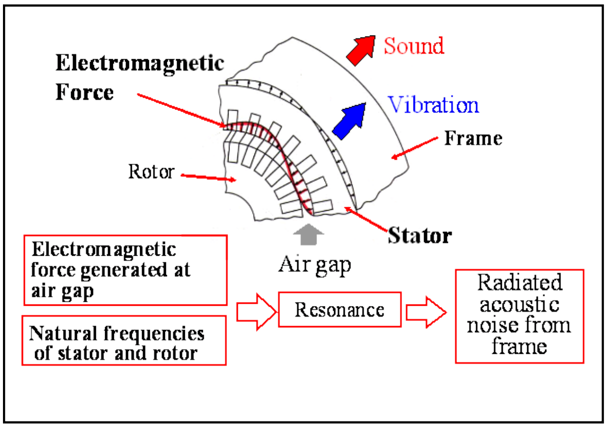

Fig.3 Mechanism of electromagnetic vibration

As shown in Fig.3, stator and rotor of the motor produce harmonic fluxes as well as fundamental flux in air-gap.
The stator m-th harmonic flux density bm is expressed as Eq. (1).

$$b_m = B_m \sin\left(\omega\ t - m\frac{\pi}{p\ \tau}x_1\right) \qquad (1)$$

The rotor n-th harmonic flux due to the stator m-th harmonic flux bn is expressed as Eq. (2).

$$b_n = B_n \sin\left[\left\{1 + \frac{n-m}{p}\right\}\omega\ t - m\frac{\pi}{p\ \tau}x_1\right] \qquad (2)$$

where bn,bm : n-th and m-th harmonic flux density, Bn , Bm : maximum value of bn and bm, p : pair of pole (P/2), τ: pole pitch, x1: stator coordinate ,P : pole, ω:angular frequency.

Inter action of these harmonic fluxes yields electromagnetic force in the air-gap.
Radial electromagnetic force by these flux, fr is expressed as Eq.(3).

$$f_r = \frac{1}{2\mu_0}\left(\sum_m b_m + \sum_n b_n\right)^2 = \frac{1}{2\mu_0}\left(\sum_m b_m{}^2 + \sum_n b_n{}^2 + 2\sum_m\sum_n b_m b_n\right) \qquad (3)$$

Electromagnetic force in radial direction produces vibration of stator and rotor core. As a result, some of this vibration emits acoustic noise in the air.
Electromagnetic FEM calculates flux distribution at rotating permanent magnet motor by non-linear static electromagnetic program. The calculated results produce radial electromagnetic force in time and in space for each frequency. These forces used as external force in mechanical FEM to calculate vibration.

2.3 Noise source of radiation noise from vibration plate

Noise source due to vibration plane is confirmed as follows.
Acoustic FEM yields acceleration of vibration on the room surface. The normal direction of acceleration of vibration on the wall is calculated at each frequency as shown in Fig.2. Propagation of the sound in the air is obtained by FEM. Boundary condition is specified by the distribution of vibration acceleration.
In infinite baffle, the round piston with radius, a, vibrates at normal direction velocity. Sound pressure is calculated from distribution of vibration, as follows.
When area , S , on the baffle at 0-z vibrates like piston, the sound pressure, p(x, y, z ; t) at outer point, (x, y, z) is obtained by Eq.(4). Velocity component at each point is u= (x', y' ; t) in normal direction.

$$p(x, y, z; t) = \rho_0 \int_S \frac{\dot{u}(x', y'; t - R/c_0)}{2\pi R} dS \qquad (4)$$

where R is the distance between inside point and observed point.
When vibration is sinusoidal, $U(t)=u_0 e^{i\omega t}$, Eq.(5) is obtained.

$$p(x, y, z; t) = \frac{ik\rho_0 u_0 e^{i\omega t}}{2\pi}\int_S \frac{e^{-ikR}}{R} dS \qquad (5)$$

where k=ω/Co

When vibrates with piston motion in radius , Eq.(6) is obtained observed point r is assumed to be larger than radius.

$$p = \frac{ia\rho_0 u_0}{r}\frac{J_1(ka\sin\theta)}{\sin\theta}e^{i(\omega t - kr)} \qquad (6)$$

where J1: first order Bessel Function.

J1 is composed of angle, θ against z-axis and radius, a. This approximate equation is effective when the distance between domain and observed point is large.
Noise power level, W, is expressed as Eq.(7).

$$W = \pi a^2 \rho_0 c_0 \left(1 - \frac{J_1(2ka)}{ka}U_{rms}^2\right) \qquad (7)$$

where Urms : effective value of vibration velocity.

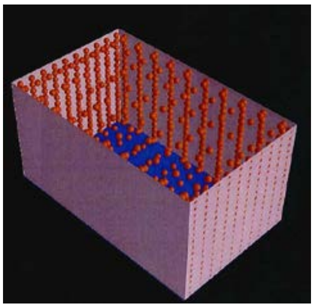

Fig.4 Room sound model of FEM

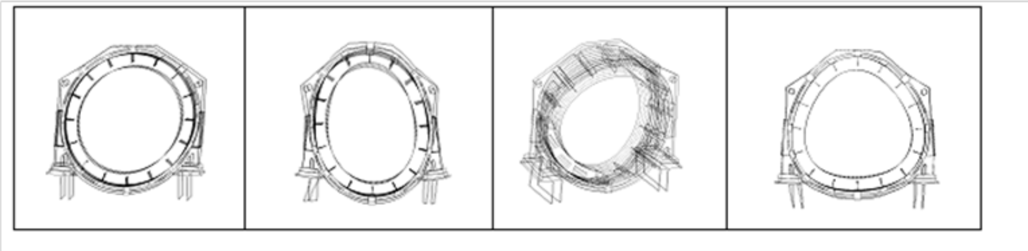

Fig.5 Electro-magnetic vibration mode on FEM analysis

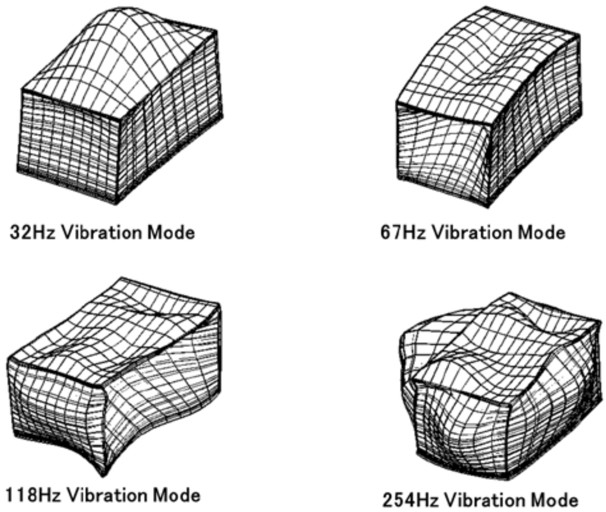

Fig.6 Vibration model of FEM

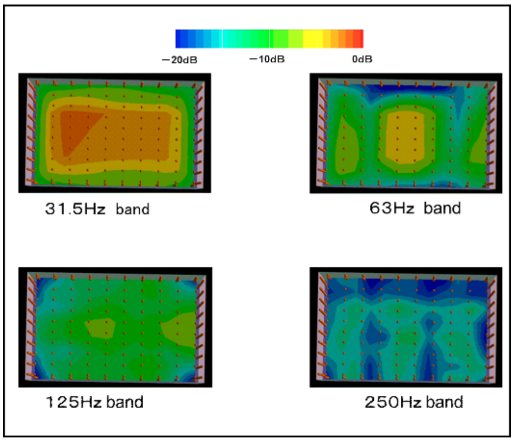

Fig.7 Sound pressure distribution of room

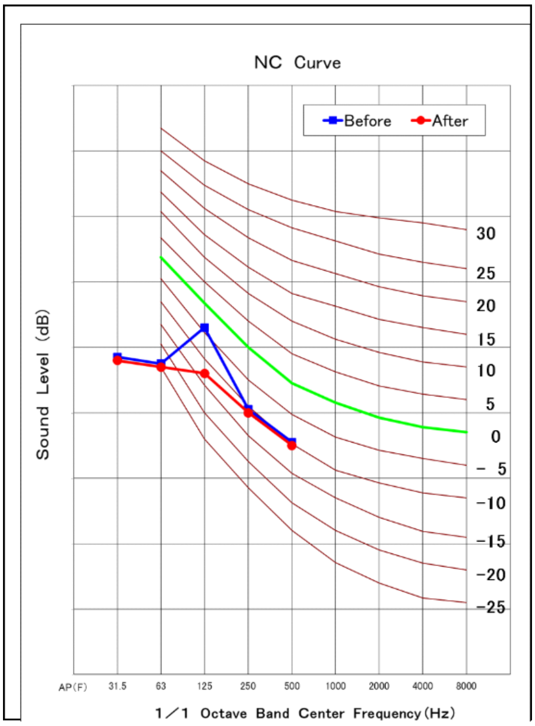

Fig.8 Noise level with octave band

From wave length and radius confirms noise source by approximate equation.

Bessel function is estimated by approximate equation with series expansion Acoustic FEM model of the room is shown in Fig.4. Eight hundred and forty red spheres stand for noise source. Sound pressure distribution is calculated from vibration of room wall in Fig.4

3. Discussion

Fig.5 shows vibration mode of the stator core due to the electromagnetic forces.

The traction machine vibrates with the frequencies, such as 32Hz, which vibrates left and right, as a fallen mode, 67Hz, which vibrates up and down, 118Hz, back and forth, and 254Hz, triangular mode.
Calculated results can predict these measured values within 3% errors.

These vibrations propagate through building construction and move the wall of the room. These vibration patterns are shown in Fig.6.

In the room, ceiling and wall vibrate by 32Hz as first bending mode.

The 67Hz is second bending mode. The 118Hz and 254Hz are third and fourth bending modes.

Acoustic analysis is shown in Fig.7, sound pressure in central cross section at 1.5 m height above room floor. The 31.5Hz and 63Hz are the first bending vibration mode. Therefore, the sound pressure at center is large.

The 118Hz and 25Hz vary sound pressure in the room. However, these sounds are likely to increase at center of the room.
At last stage, the sound level is assessed by NC(Noise Criteria) curve, as shown in Fig.8.
According to the first analysis, sound level of 125Hz is larger than expected value by 70dB in simulation. (Before points)

We reinforce the machine beam shown in Fig.1. The sound at 118Hz, back and forth vibration, is reduced as shown by NC carve in Fig.8. (After point)

These procedures confirm the synthetic simulation method from motor, that is, traction machine, to room noise through propagation of the building, at designing stage.

4. Conclusions

We present synthetic sound simulation procedure at designing stage. This includes traction machine vibration, ant-vibration construction and room noise.

Following results are summarized.

(1)Vibration of the room wall is obtained for each frequency of the vibration of traction motor.
This vibration communicates through the building construction.

(2)Applied FEM can simulate wave motion caused by vibration of room wall. This FEM yields vibration mode of traction machine and of room wall. Sound distribution of the room is also obtained.

(3)Sound level varies in the room dependent on the vibration mode of room wall. Sound level is large at the center of room.

(4)This procedure provides estimation of sound level in the room. In the frequency range of large noise, Noise is assessed using NC curves and effective measure is proposed.

Here after, we will expand this process to other cases and improve the precision. We also promote the noise reduction.

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