전자동 세탁기의 동적거동에 관한 연구

A Study on the Dynamic Behaviour of an Automatic Washing Machine

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1. Abstract

This paper describes the vibration simulation result of the washing machine. The washing machine mainly consists of the spinning basket, the tub which is connected by the shaft, and the four supporting rods from the tub. The spinning basket utilizes the liquid balancer to control the unbalance force. Therefore, one of the points for modeling is the construction method for the liquid balancer. This paper describes the modeling method and the simulation performance from the comparison with the experimental result. As the simulation result has a good agreement with the experimental result, it is possible to predict the transient procedure during the spinning course.

2. Introduction

A Washing machine is to be classified into a drum type, an agitator type, and a pulsator type. In the drum type, the spinning tub rotates with the vertical axis to gravity and the clothes tumble upward and downward. And, in other two types, the spinning tub rotates in the gravity direction. During the washing, these washing machines use the rotational force of a pulsator or an agitator located in the center of the spinning basket. The rotational force makes water flow in the spinning basket for the cleaning. In this study, the pulsator type washing machine is the target to investigate the dynamic behavior.

The pulsator type washing machine utilizes the centrifugal force of rotation while dehydrating. When cloth unbalance occurs in the spinning basket, the big vibration occurs during the spinning course. This vibration problem becomes serious as the capacity of washing machine is bigger and the rotation speed is higher. A liquid balancer is utilized to overcome this phenomenon. The liquid in the balancer moves to the opposite side of unbalance automatically when the rotational speed is higher than the critical speed of the spinning basket.

In the 1980's, a liquid balancer is proposed for reducing vibration and its analytical study is performed[1]. Kim, Chae Won[2] considers a liquid balancer and carries out the dynamic analysis with regard to various rotational speed, the damping ratio and the stiffness of the suspension system, and suggests the design parameter for reducing vibration of transient and steady state. In above studies, since a liquid balancer is modeled as an external force, it is difficult to simulate the transient phenomenon such as the starting time. In this study, the washing machine is modeled as a 3 dimensional 6 D.O.F. and the liquid in the balancer is modeled as the lumped masses to simulate the transient and steady state behavior. This paper describes the modeling method and the simulation performance from the comparison with the experimental result by the commercial dynamic analysis software(ADAMS) .

3. Structure of an automatic washing machine

The structure of an automatic washing machine is shown in Figure 1. There are the spinning basket and the tub which contains water during the washing. And the tub is hanged on the corner of the outercase by four supporting rods. The spinning basket rotates along the spinning axis by motor which is connected with the shaft system. The liquid balancer is attached on the upper side of the spinning basket. The pulsator which stirs the water is located on the bottom of the spinning basket. The absorber works as a vibration reducer of the tub when passing the transient region.

4. Principle of a liquid balancer

As the spinning basket rotates, the liquid containing the salt in the balancer is reacted by the rib in the balancer so that the centrifugal force makes the liquid located on the side wall of the balancer. As the result, the profile of the liquid is formed as the ring shape as shown in Figure 1. When the rotational speed of spinning basket, ω, is higher than the critical speed of the spinnig basket, ω_n, as shown in Figure 1, vibration occurs corresponding to the eccentricity indicated as e. The liquid surface is formed as ring shape with the center of vibration, O. Consequently, the liquid moves to the opposite side of cloth unbalance and its equivalent centrifugal force compensates the centrifugal force due to the cloth unbalance. And when rotational speed, ω, is lower than the critical speed, ω_n, the center of vibration, O, moves to the opposite side of cloth unbalance so that the liquid works as an unbalance. However, because of the low ω_n, which is normally to be 1~2 Hz, the liquid surface is hard to stand vertically and move. Therefore, this can be controlled with adjusting the motor torque and the damping ratio of the absorber to overcome this phenomenon.

5. Modeling of the washing machine and the liquid balancer

The simulation is executed by the dynamic analysis software. It performs the simulation with the rigid bodies connected by the joints. The joint makes relative motion between the mutual parts. The typical joints are a spring and a damper.

The outer parts(motor, tub) are connected by the fix joint each other. So, the whole part is regarded as one rigid body. The outer parts are connected to ground by the four rods. The inner parts(shaft, pulsator, spinning basket, balancer housing) are rigidly connected each other similar to the outer parts. The whole inner part is connected to the outer parts with a special joint which represents the elastic deformation of the inner parts. This special joint is composed of the dummy element, bushing and spherical joint. The dummy element possesses nearly zero mass. The outer parts are connected with this dummy mass by the revolute joint, and the dummy element is linked to inner parts with bushing and spherical joint.

The liquid balancer controls the vibration of the tub as previously discussed. As the spinning speed gradually increases, the center of gravity of the liquid moves to the opposite side against the unbalance mass.

Though the liquid behavior should be modeled as a continuous body, it is difficult to represent the hydrodynamic property into the software. In order to simulate this phenomenon, the eight lumped masses are applied to simplify the hydrodynamic behavior.

The lumped masses are linked to the center line of the spinning basket with revolute joints and rotational spring-dampers. The forces from rotational spring-dampers move the lumped masses while rotating. The virtual force is also applied to the lumped masses to avoid the cross-over of lumped masses. This virtual force works when the distance between the lumped masses reached to the criterion defined by the user. When this criterion is controlled, the equivalant balancing force is to be controlled.

When the liquid balancer is modeled as the eight lumped masses, the distance criterion of the virtual force and rotational spring damper coefficient are updated to represent the real liquid balancer behavior determined by the experiment.

6. Experiment

The experiment is performed in order to verify the simulation modeling of the washing machine. Figure 2 shows the experimental apparatus. Three accelerometers are attached on the upside, middle and downside of the tub. These horizontal acceleration signals are measured simultaneously and are converted to the displacement by the charge amplifier. The unbalance mass is attached on the topside of the spinning basket first time and next time on the bottom to represent the unbalance.

The rotational speed of the spinning basket varies linearly to 1000 rpm until 30 seconds. The transient status occurs while this 30 seconds speed ascent

7. Results of correlation between the simulation and the experiment

Figure 4 and Figure 5 show the displacement signal of the tub along a time scale when the unbalance mass attached on the spinning basket. The vertical line indicates the displacement amplitude in millimeter. The first peak at around 2 second indicates the transient status when the starting up. This region includes the critical speed of the spinning basket. After passing the critical speed, the system tends to be stable. In case of Fig. 4, the displacement is gradually bigger after 15 second. This phenomenon comes from the elastic deformation of the spinning basket. However, in the case of bottom unbalance mass condition which is indicated in Fig. 5, this phenomenon becomes small.

From these observations, when the unbalance mass is attached on the topside of the spinning basket, the displacement of the upside of the tub is bigger than the other positions. Therefore, the tub vibration is to be observed as a conical mode type.

As the peak-to-peak is the most important parameter to evaluate the vibration perfomance of the washing machine, the peak-to-peak value in each case is summarized in Table 1. The simulation result has a good agreement with the experimental result within 18% error. Also, the trend and the signal magnitude are similar to each other.

Therefore, this ADAMS® modeling method is to be utilized for estimating the washing machine vibration characeristics according to the design changes.

8. Conclusions

The dynamic modeling of the automatic washing mashine is investigated to simulate the vibration property in the case of both the transient and the steady state. Being based on the investigation, the conclusions are drawn as follows :

The correctness of the dynamic modeling of the automatic washing mashine is confirmed from the comparison of the simulation with the experiment.

The liquid balancer is to be modeled as the lumped mass and its perfomance is to be controlled by modifying the distance criterion of the virtual force and rotational spring damper coefficient.

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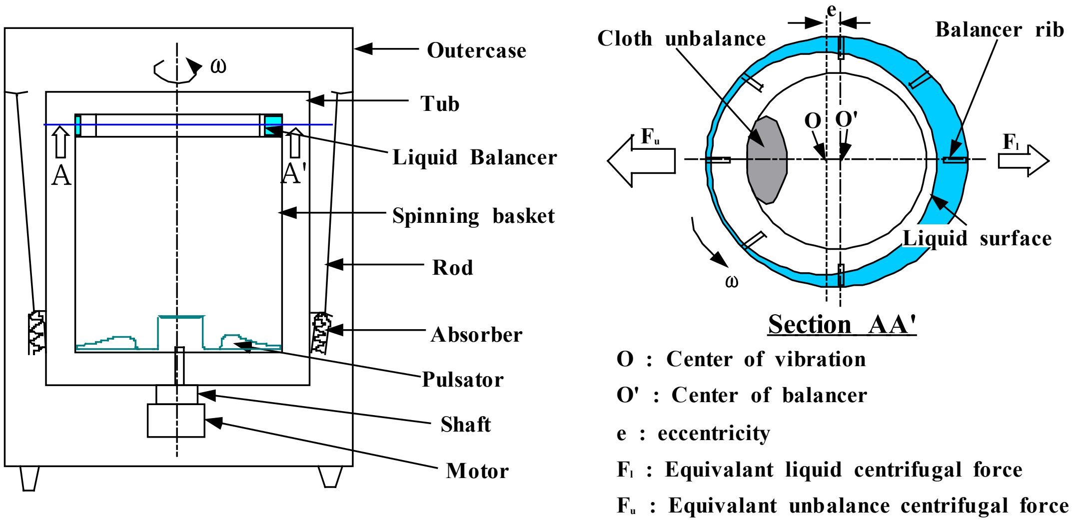


Figure 1

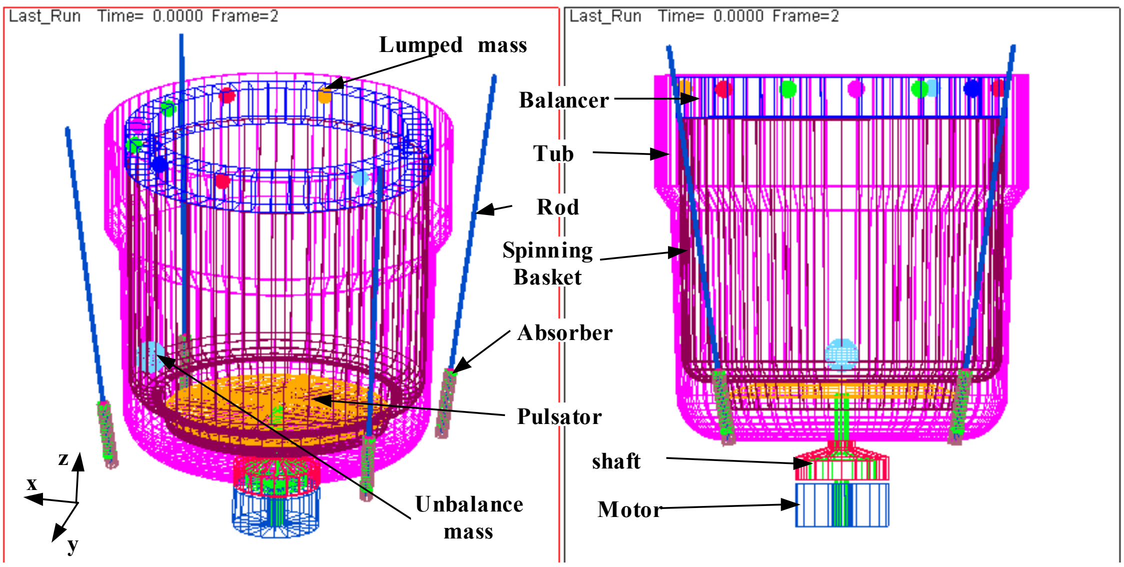
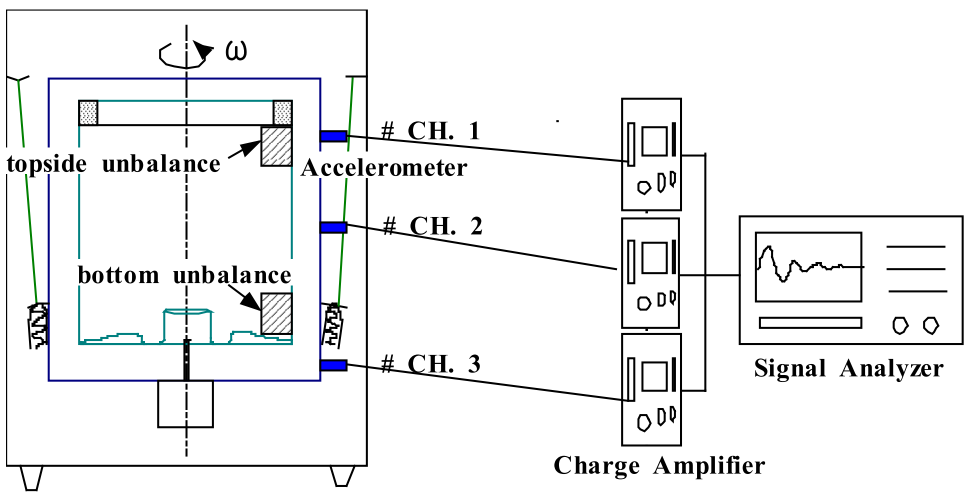


Figure 2



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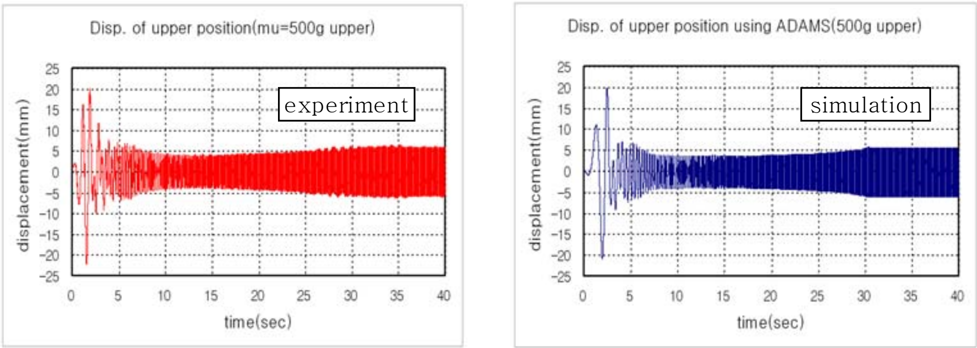

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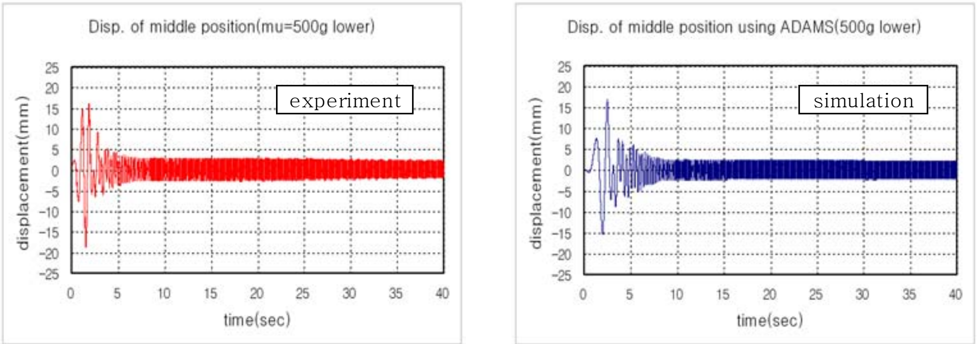

Figure 5

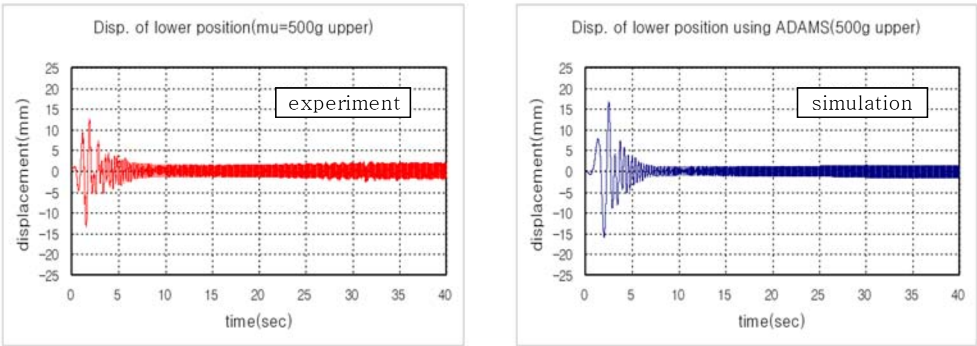

Figure 6