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Reduction in vibration of a washing machine by means of a disengaging damper

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ABSTRACT

This paper presents a new semi-active technique for reducing the vibration of a washing machine frame during the spin cycle. A new electromechanical damper was proposed for this purpose. The damper is disengaged during the spin cycle, which results in the reduction of the vibration of the frame. A unit for switching the state (on/off) of the damper is presented. A dynamic model of the washing unit was developed to simulate the motion of the system after the damping forces are disengaged. Numerical results proved that there is no danger of the collision between the drum and the frame. The model also allowed estimation of the forces transmitted from the drum onto the frame through the suspension. The model was validated by the experiments carried out at a stand dedicated to measuring the vibration of the washing unit suspended on original and new dampers. The reduction of the frame vibration without perceptible increase in the drum vibration was observed.

1. Introduction

The operation of rotating machines is frequently accompanied by free masses whose weights or positions vary in time. Examples of these are rotary machines such as concrete mixers, centrifuges, spin dryers, separators and washing machines. The balancing of such machines using correction masses is not effective, as the load may distribute on the surface of the drum in a different way at each spin cycle, and may have a different weight at each use; hence the problem of vibration is recognised by both the users and the producers. Engineers have carried out studies aimed at either reduction or minimization of this influence on the environment. The problem of damaging vibrations in domestic washing machines has been widely considered. The solutions can be divided into two categories:

- Methods consisting in the balancing of the drum
  - using active moving masses,
  - using free masses.
- Methods consisting in semi-active change of parameters of the drum suspension.

Examples of balancing the drum by means of active moving masses are presented in [1,26–27]. The masses are moved by means of linear or ring actuators along the radius or circumference of the drum, in order to shift the position of the mass centre of the system. Balancing using free masses was described in [2]. A ring, partially filled with liquid, is mounted at the circumference of the tube. The aim of the structure is to shift the mass centre toward the axis of rotation with the inertia of the rotating liquid. The paper [3] considers theoretically the reduction of vibration in a one degree of freedom (DOF) system using free masses. Free balls are placed in the container attached to the upper surface of the system vibrating along the vertical axis. The mutual collisions of the balls result in the passive reduction of vibration. Although the paper considers a one DOF system, the method can be adapted to systems with many degrees of freedom. As a combination, to some extent, of the two foregoing methods, one of the main producers of washing machines (Samsung) worked out a method of vibration reduction by means of free balls moving in a ring attached to the circumference of the drum. The positions of the balls are synchronized with the position of the mass centre of the load so that the mass centre of the whole system automatically moves towards the axis of rotation. As a consequence the problems related to storing and sealing of liquid in the balancer are eliminated. These studies resulted in a patent [4] and introduction of the idea to production under the trade name VRT®. Nonetheless, because of the relatively small weight of the balls compared to the weight of the load, only a small reduction of the vibration of a washing machine is achieved, and the problem remains still unsolved. The advantage of the method is its simplicity and the lack of electronic control, as in the spin cycle the balls take the positions opposite to the mass centre of the load automatically, according to the laws of physics. However, this phenomenon only occurs at rotor speeds above resonance.

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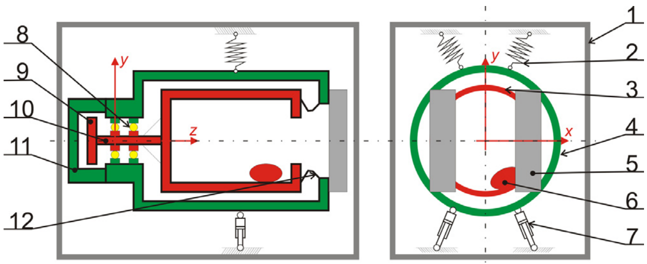

Fig. 1. Scheme of parts of a Samsung *WF0804* washing machine.

The attention of many researchers is focused on ensuring continuous regulation of the mechanical parameters of drum suspension. Semi-active regulation of the damping forces is the main branch of these studies. Many papers [5–7] present solutions in which magnetorheological fluid (MRF) was used to control damping force. MRF changes its rheological properties under action of changes in the intensity of a magnetic field. Using an induction coil one can fluently control the viscosity of the fluid and, as a consequence, the damping force [8]. The disadvantage of devices utilizing this fluid is continuous current consumption. Depending on the type of the device, current intensity varies from 1 to 6 A. Moreover, because of the low efficiency of induction coils, one has to solve the problem of carrying away the heat generated by the wiring. Because of these mainly economic reasons, despite relatively effective reduction in vibration, methods utilizing MRF fluids have not yet been applied in the production of washing machines. Intensive studies on MRF are still carried out to overcome these difficulties.

This paper presents a new semi-active technique for reduction of vibration of the washing machine frame during the spin cycle. Some studies have indicated that the damper can be disengaged in the spin cycle, which results in the reduction of the vibration of the frame. This was achieved by applying dampers filled with MRF [5–7]. This paper presents a new construction of electromechanical damper, developed for the purposes of these studies. The electronic control system for switching the state of the damper (engaged/disengaged) is very simple, and the current consumption is low. Before the damper was manufactured, a dynamic model of the washing unit was worked out in order to simulate its motion after the disengagement of damping forces. Numerical calculations were carried out to assess whether there was a danger of the collision between the drum and the frame. The model allowed also estimation of the forces transmitted from the washing unit to the frame through the suspension. The numerical results were validated by the experiments.

2. Washing unit description

The front-loaded horizontal drum type of the domestic washing machine WF0804 (Fig. 1) produced by Samsung is considered here. The geometric and mechanical parameters of the washing unit are presented in [9,10]. A specific feature of the machine is direct drive brushless DC motor, which produces high torque at low rotational speed. Therefore the drive is mounted directly on the shaft of the drum — no reduction gear is used between the drive and drum. The advantages of such a solution are lower inertia of the connection between the shaft and drum, and simpler construction. Furthermore, in a classical construction with a transmission belt, the drive rotates faster than the drum. The lack of this transmission eliminates the modes of higher frequencies in the spectrum of drum vibrations. The maximum allowed rotational speed of the drum is 1600 rpm. The maximum laundry load is 8 kg.

The tube (4) is attached to the frame of the washing machine (1) by means of the suspension, i.e. two springs (2) attached at the top of the tube and two friction dampers (7) placed at the bottom of the tube. The stator of the drive (11) is also an element of this part. The rotor (9) transmits the torque from the drive to the drum (3) through the shaft (10). For test purposes an unbalanced mass (6) is attached to the inner surface of the drum and imitates the laundry. The shaft is embedded in the frame of the drum by means of a pair of single row bearings (8). A rubber lip (12) between the frame and the front window of the drum prevents water leakage. The structure is weighted with two concrete blocks (5) mounted at the loading front of the drum in order to increase the global mass of the system. The objective of these blocks is to reduce the influence of the inertia forces by increasing the mass of the washing unit. Moreover, these blocks counterbalance the drive. Nonetheless, the presence of the blocks causes higher transport costs and increases the size of the machine.

3. Dynamic model of the washing system

A dynamic model of the washing unit was developed in order to numerically simulate the disengagement of the damper in the spin cycle. Most researchers model the drum as a discrete system. The authors of [11] introduced a simple model, in which the drum is a two DOF- solid body, in order to describe the phenomenon of the washing machine moving along the floor. In [1], the authors analysed the motion of the mass centre of the drum in three dimensional space in order to propose a theoretical method of drum balancing by means of active balancers. Neither of the foregoing models [1,11] make any distinction in the washing unit between the drum (the system of rotating masses) and the tube (the system of nonrotating masses). Moreover the suspension is neglected and the numerical solutions were not verified experimentally.

A more complex mathematical description was presented in [12], where the authors analysed a six DOF body with all the elastic and damping elements of the suspension. The aim was to compute the modal frequencies of the drum for each degree of freedom. This paper focused on the problem of finding the optimum parameters for the suspension, as dampers which are too rigid cause perceptible vibration of the frame, whereas suspension which is too flexible may result in collision of the drum and frame of a washing machine. The authors described the motion of the drum with three DOF in order to determine one constant dissipation coefficient that was optimal for both washing and spin cycles. Nonetheless, the experimental validation of the theoretical and numerical considerations has not been carried out. An example paper in which experimental validation was performed is [13]. The drum was modelled as a two DOF solid body moving in the frontal, vertical plane. The suspension elements were included. The parameters of the model were identified numerically using a genetic algorithm. A more complex model of the drum was presented in [14]. The rotating part of the washing unit (the drum) as well as the nonrotating part of the washing unit (tube) were described by a model with twelve DOF. It was assumed that forces acting along the rod of the drive can be neglected and that the bearing connecting both units can be treated as a rigid body. The authors pointed out that the motions in many of the degrees of freedom are of small amplitude, and their omission does not significantly affect the accuracy of the solutions, while on the other hand, this omission simplifies the description [15,16].

Numerical integration of the dynamic equations of the system defined by twelve DOF is very time consuming. In the present paper the authors worked out their own dynamic model of the washing unit on the basis of a literature review. The rotational motions have to be regarded to simulate reliably the motion of the drum with disengaged damping. Therefore the models allowing for displacements of the drum only are too simple, whereas the model presented in [14] is complex and difficult to implement.

The original damper applied in the washing machine is presented in Fig. 2.