**CONTROL ID:** 2200033

**TITLE:** Estimating unbalance mass of vertical axis washing machine by measuring current ripple of PMSM motor

**AUTHORS (LAST NAME, FIRST NAME):** Jung, Kyung-Tae[1]; Chai, Seung-Hee[1]; Kim, Yong-Beom [1]; Hong, Jung-Pyo [1]

**INSTITUTIONS (ALL):**

1. Automotive Engineering, Hanyang University, Seoul, Seoul, Korea (the Republic of).

**ABSTRACT BODY:**

**Digest Body:** I.Introduction Lately, as the desire for comfortable and pleasant living environments has grown because of improvements in the standard of living, interest in the reduction of vibration and noise of electric appliances has increased. In the case of washing machines, in particular, the drum of the machine rotates at a high speed during the dehydration mode, and thus, the problem of vibration arises. The vibration of rotary machines not only shortens their lifecycle and produces noise, but also causes discomfort to those nearby. Therefore, a great deal of effort has been devoted to reducing this vibration. The load of the washing machine is primarily dependent on the weight of the laundry. However, unbalance mass is not determined as a simple function of the increase in weight. During the washing process, laundry is often driven to one side of the machine because of a tangle. In general, such a change in the load alters the magnitude of the current flowing through the electric motor, and thus, proper control would necessarily depend on the size of the change. Additionally, structural sources of unbalance mass inevitably exist in the steps of designing and manufacturing washing machines and the unbalance mass of the laundry causes the vibration in the spin-dry mode. To determine the unbalance mass, adding an additional sensor is one solution; however, this additional cost would likely be passed on to the consumer, and thus, a method of accurately determining the unbalance mass without increasing the cost is needed. The vibration issues related to the mechanical structure of the washing machine were examined in [1; the assumptions of [1] regarding the unbalance mass when using a mechanical sensor were studied in [2]. In [3], a mathematical model of a vertical axis washing machine including the unbalance force was suggested. In this study, first, an equivalent circuit of a permanent-magnet synchronous motor (PMSM) and a dynamic model of a washing machine are derived; second, a method for deriving the unbalance mass from the ripple of the current flowing through the electric motor is suggested; and finally experimental verification of the results are conducted. II.Analytical models (1) presents a d-q-axis equivalent circuit of a PMSM that includes core loss; the voltage and torque equations based on this circuit are as follows [4]. $v_d = R_a i_{od} + (1+R_a/R_c)V_{od} + pL_d i_{od}$, $v_q = R_a i_{oq} + (1+R_a/R_c)V_{oq} + pL_q i_{oq}$ (1) $v_{od} = -\omega_e L_q$, $v_{oq} = \omega_e L_d + \omega_e \Psi_a$ (2) $T_e = P_n[\Psi_a i_{oq} + (L_d - L_q) i_{od} i_{oq}]$ (3) Here,$v_d$ and $v_q$ refer to the d- and q-axis terminal voltage, respectively; $i_{od}$ and $i_{oq}$ refer to the d- and q-axis current excluding core loss, respectively;$R_a$ and $R_c$ refer to the winding resistance and equivalent core-loss resistance, respectively;$\Psi_a$ refers to the flux linkage of the permanent magnet; $P_n$ refers to the pole pair; $p=d/dt$;$T_e$ and refers to the motor torque. $\theta(t)=\int(\omega_r - \omega)dt+\theta_0$ (4) $F_t=m_{ub}g\sin\Phi\sin\theta$ (5) $T_e = J_z d\omega_r/dt + m_{ub}gR\sin\Phi\sin\theta + T_f$ (6) $\triangle i_{oq} = (2|m_{ub}gR\sin\Phi| + T_f)/(P_n\Psi_a)$ (7) Fig.1 shows the washing machine system. As the drum of the washing machine rotates, the rotation axis is tilted because of the centrifugal force of the unbalance mass [3]. $\Phi$ refers to the angle between axis and axis; R refers to the radius of the drum; $m_{ub}$ refers to the unbalance mass;$T_f$ refers to the combined friction torque and cogging torque; $J_z$ refers to the moment of inertia of the drum. Additionally, (5) determines the tangential force applied to drum by the unbalance mass. In the steady state, when the electric motor is controlled according to id=0 vector control, a current ripple can be obtained, as defined by (7). Then, the current ripple caused by $T_f$ can be measured by running a washing machine without any laundry, and $T_f$ is kept as a constant. III.Experiment and Simulation result Because the magnitude of the current ripple is irregular while the motor rotates, a representative value was determined using the moving average method ; it was confirmed that the value converged after approximately 30 iterations, as shown in Fig. 2 (a). Fig. 2 (b) shows the relationship between unbalance mass and current ripple for different rotational speeds of the drum of the washing machine. Fig. 2 (b) indicates that the proposed equation in (7) is correct. Errors occur because the mass is not a point mass and the current of the experimental value does not reflect the current of the core loss. Additional errors occur, because of the structure of the suspension rod, is irregular while the drum of the washing machine rotates. IV.CONCLUSION Estimating unbalance mass of vertical axis washing machine by measuring current ripple was presented. The vibration and noise of a vertical axis washing machine are caused by complex factors including the structure, environmental conditions, and the unbalance mass. The reproducibility of these factors is also irregular. Unbalance mass, in particular, might occur because of a tangle during the washing process, and thus, the unbalance mass should be either predicted or measured before the spin-

dry mode. Although the addition of a sensor or the use of complicated algorithms have been proposed to measure the unbalance mass, this study suggested a method of determining the unbalance mass using the current ripple without requiring additional sensors and experimentally confirmed its validity. As a result, current ripple is one of the key factors for estimating unbalance mass.

**References:** [1] Conrad, D.C.; Soedel, W. On the problem of oscillatory walk of automatic washing machines.J. Sound Vib. 1995, 188, 301-314. [2] Ray Martin Y. Yuan, Ali Buendia and F. Ashrafzadeh. Unbalanced load estimation algorithm using multiple mechanical measurements for horizontal washing machines. Oct 2007. [3] H. W. Chen and Q. J. Zhang, Stability analyses of a vertical axis automatic washing machine without balancer, Journal of Sound and Vibration, 329 (11) (2010) 2177-2192. [4] J. Y. Lee, S. H. Lee, G. H. Lee, J. P. Hong, and J. Hur, "Determination of parameters considering magnetic nonlinearity in an interior permanent magnet synchronous motor," IEEE Trans. on Magnetics, vol. 42, no. 4, pp. 1303-1306, April 2006.

**KEYWORDS:** Washing machine, Unbalance mass, PMSM, Current ripple.

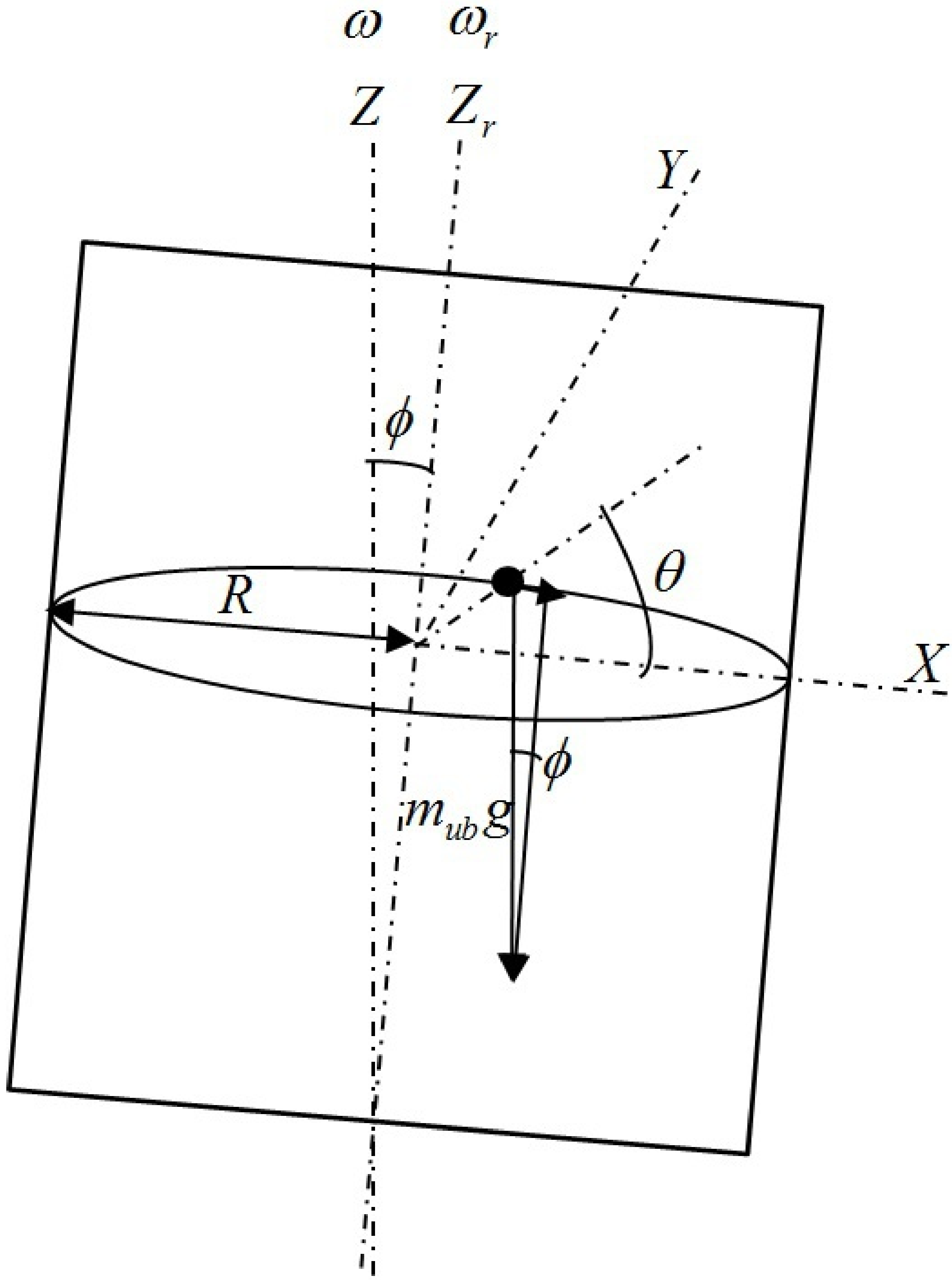


Fig. 1 Unbalance mass in vertical axis the washing machine

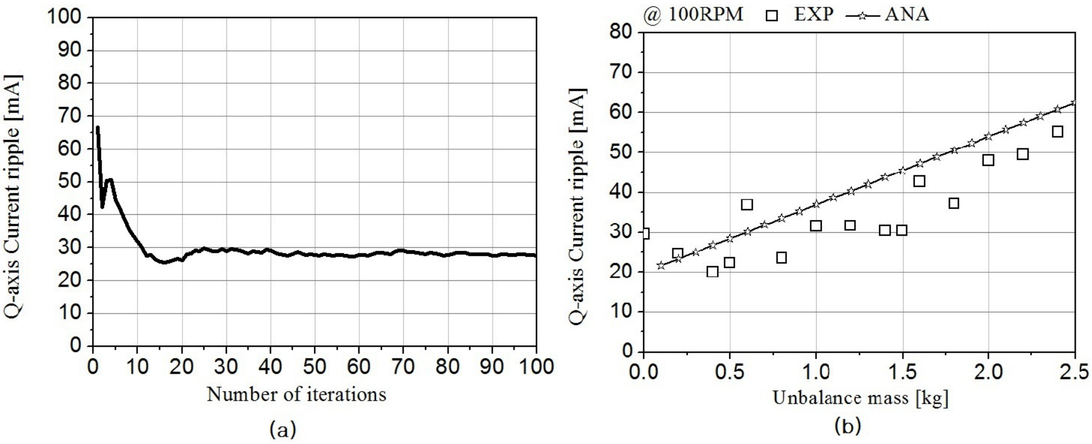


Fig. 2 (a) Current ripple and moving average method (b) Unbalance mass and current ripple

**CONTACT (NAME ONLY):** Kyung-Tae Jung
**CONTACT (E-MAIL ONLY):** ktjung8310@hanyang.ac.kr
**PRESENTATION TYPE:** Poster
**CURRENT CATEGORY:** 4. Electric machines, power devices & electromagnetics
**CURRENT SUB-CATEGORY:** c. Power and control magnetics