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REDUCTION OF NOISE AND VIBRATION OF FRONT LOADING WASHING MACHINE IN SPIN-CYCLE

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Abstract

Water is pumped out from the washing machine during spin cycle by drain pump, which is the cause of noise and vibration. These noise and vibration may be characterized by three main sources. First is the fluid force caused by the rotating blade hitting the surface of the water. Second is the force created by the unbalance in the rotating structure and third is the electrical force caused by motor.

The objective of this paper is to minimize theses forces transferring from drain pump to washing machine. These forces were characterized using multi-physics analysis and verified them through vibration and fluid experiments.

Also design sensitivity analysis for optimizing drain pump mount position and properties were conducted. The suggested optimal design method for mounting the drain pump was tested and improvements were confirmed.

1. INTRODUCTION

Noise and vibration are critical problems in washing machines as laundry is rotated in a basket. Numerous home appliance companies have put in much efforts to solve this problem but there is still large room for further improvements especially in the spin and the drain cycles.

Lately, large improvements in spin cycles were made due to replacement of liquid balancers with ball balancers but the performance improvement in the drain cycle have more or less been stagnant. Therefore, relative interests in noise and vibration reduction technology have been shifting from spin cycle to drain cycle.

Noise and vibration improvements on drain pump system are not a simple matter because traditional approaches have been from the structure and dynamic point of view. However, drain pump deals with multiphase fluid including air and water which requires fluid dynamics to be considered together with other traditional approaches. There are two kinds of noise generated by drain pump. One is relatively normal noise during steady-state operation and the other is abnormal noise caused by mixed multi-phase fluid (air and water mixture) and impurities. The latter is what must be improved. As irregular pressure changes occur inside the drain pump housing during impeller rotation, these changes cause not only noise but also excite the frame and cause vibration of entire system by going through the pump bracket and mount structure.

Therefore, this paper will attempt to characterize the transfer force, vibration and noise of drain pump through fluid, structure/vibration and noise analysis. Also, simultaneous approach will be taken from both the structural and fluidic point of views to draw out improvements in floor transfer, noise and vibration of drain pump.

2. IDENTIFICATION OF DRAIN PUMP SYSTEM

Until now, the effect of design and operating condition of drain pump with relations to noise and vibration were not analyzed thoroughly for them to be optimally designed. Therefore, it is necessary to determine the source of the problem and conduct parameter study not only to improve pump performance but also to find contribution on vibration, fluidic noise, and abnormal noise to suggest a design methodology for design of drain pump.

In order to redesign the drain pump, both experiments and analysis were conducted simultaneously on structure and fluid movement as shown in the flow chart in Figure 1.
Current performances (transfer force, vibration, and noise) of individual parts were set as reference and based on these, improvements were searched from 2 directions. First is from the structure and vibration point of view. The source of problem of drain pump system is the pump motor and by minimizing the transfer of force from the motor to the mounting structure, floor transmission force and frame exciting force may be minimized. Second, an attempt to minimize excitation of pump case due to fluid force was conducted. As drain pump operates during the drain cycle, water rushes into the pump case while the impeller rotates to remove water from the pump case. The water rushing into the pump case cause fluid forces and applies pressure on the pump case which leads to drain pump vibration and noise. Therefore, noise and vibration can be minimized by decreasing the fluid force that excites the pump case.

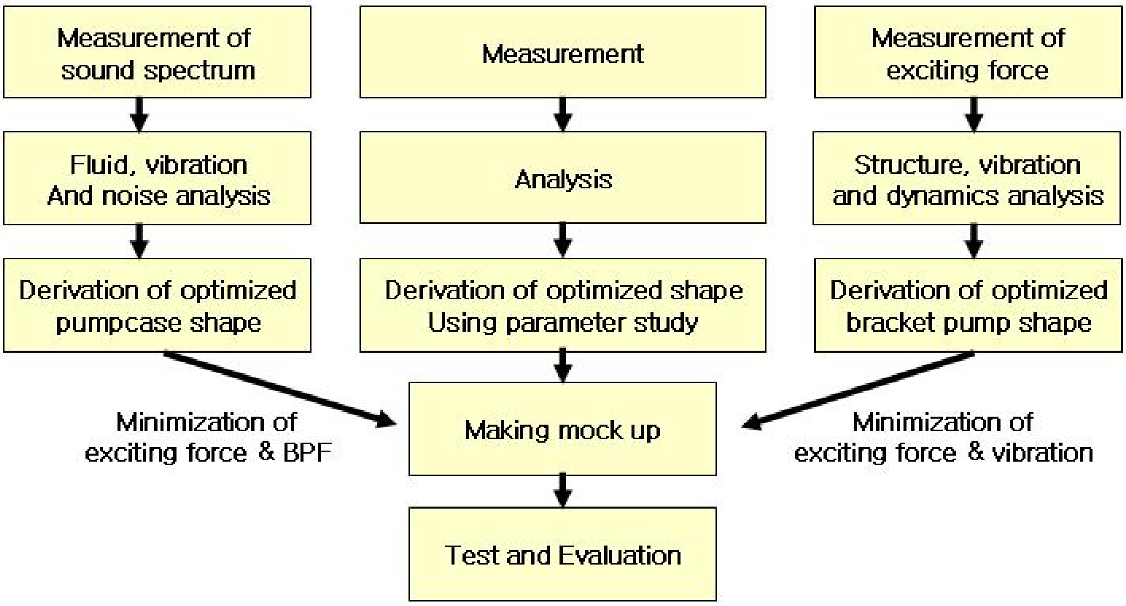
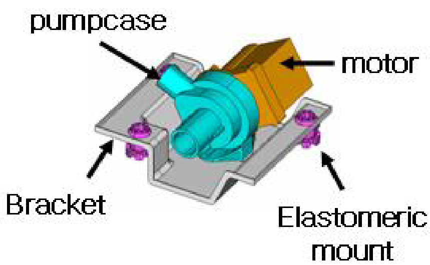


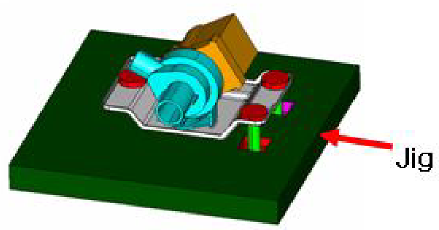
Figure 1. Flow chart.

The drain pump system consists of four parts, elastomeric mount, bracket pump, pump case and motor, as shown in Figure 2(a). Experiments were conducted to measure the excitation force from the motor and measure overall noise and vibration. Parts currently in use were tested to locate the source and background of the excitation force, noise and vibration. Based on the results, dynamic computer simulation was used to optimize the location and shape of the bracket pump. Also, for verification and validation, actual mock-up samples were built and tested compared to current system.

2.1 Exciting force measurement

During drain cycle, drain pump motor is activated which cause the impeller to rotate and drain water through the drain hose to outside the machine. Three main sources of excitation force can be categorized during this cycle. First is the force created by the fluid flow from the washing compartment (drum of washing machine) to the pump case. Second is the electrical excitation force due to motor rotation which may be the biggest contributor of noise and vibration. Last is the excitation force created by the unbalance within the rotating system.
In order to measure the excitation force from 3 sources mentioned previously, a test jig was built as shown in Figure 2 (b). A force transducer is attached on each of the elastomeric mounts to measure the force.





(a) **(b)**

Figure 2. (a) Structure of drain pump, (b) jig for measuring excitation force.

2.2 Vibration and noise measurement

Inside a semi-anechoic chamber, noise measurement was conducted by placing microphones one meter away from front and two sides of the machine. Data was collected for one minute. Also, an accelerometer was place on the top of the frame to measure the frame vibration during noise measurement. Schematic is shown in Figure 3.

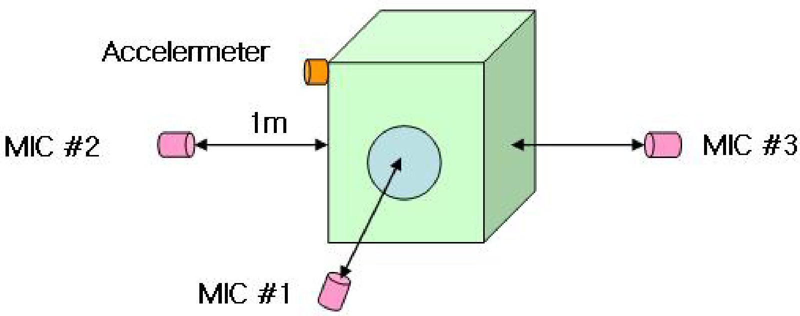


Figure 3. Schematic of noise and vibration measurement setup.

3. ANALYSIS

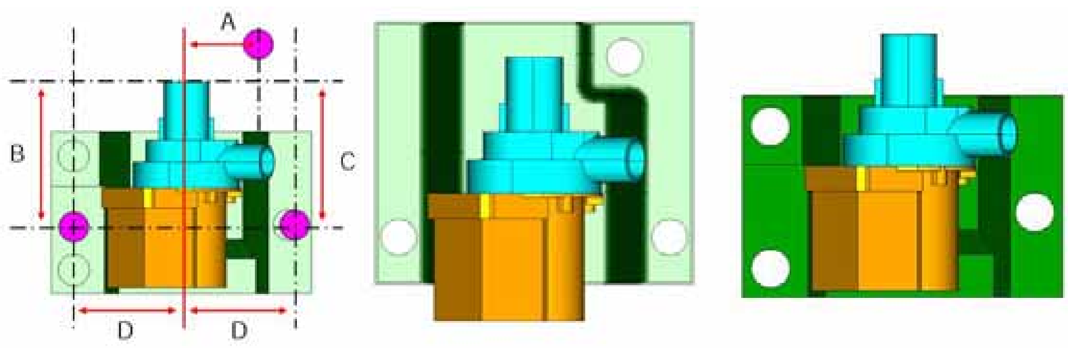
3.1 Dynamic analysis

Based on measurement of excitation forces on the drain pump from 2.1, optimal mount position of the pump bracket was searched. First, current production pump mount system was analyzed using ADAMS dynamic simulation tool with input conditions from measurement data from 2.1. Three force measurements were separated into 2 moment parameters and 1 force parameter. The rolling (movement of left to right) and pitching (movement of front to back) movements were categorized as moment, and bouncing (vertical movement) movement as force. Using the dynamic analysis, peak-peak results were calculated, and correlated with actual results. Once the model was matched, new drain pump location optimization of performed.

First of all, As shown in Figure 4(a), A, B, C, D, height, and position were selected as critical parameters. Minimizing the sum of mount excitation force was used as target to find the optimal values for these parameters.

3.2 Fluid, noise and vibration analysis

Critical factors including blade length, blade number, rotating axis, and outlet direction were selected to minimize the unbalance force from fluid flow. ANSYS-CFX was used to conduct computational analysis of excitation force and noise from fluid flow. In addition, force results from computational fluid analysis were used to excite the center of gravity on the drain pump to monitor the frame vibration due to fluid flow.



(a) **(b)** **(c)**

Figure 4. (a) Optimization variables, (b) front mount position, (c) side mount position.

4. COMPARISON BETWEEN EXPERIMENTAL AND ANALYTICAL RESULTS

4.1 Fluid analysis results

Fan type, operating point, and surrounding structures are generally the factors that affect the performance of drain pump. Among these, impeller inside the pump case (fan type), inlet and shroud shape (surrounding structures) were selected as critical factors. In order to see the effect of these factors on pump performance and noise, ANSYS CFX was used to perform fluid-noise concurrent analysis. The results are shown in Table 1. Analysis show that factors that affect the drain pump lift force and noise are the impeller length and height. Also, factors that affect the excitation force due to fluid movement are rotation center shit, impeller height and length.

Therefore, efficiency, performance, and unbalance force would be greatly improved by controlling the design factors of the impeller. However, performance and noise/unbalance force are in trade off relationship thus product performance conditions such as installation condition must be set before attempting to design a reduced noise and unbalance force system.

Table 1 Fluid analysis results

case/shape	No. of impellers	head, [m]	overall, [dB]		Max. unbalance force, [N]
			SPL	SWL	
default shape	4	2.64	92.0	63.7	6.34
impeller number	3	2.26	91.3	63.0	7.60
center shift	4	1.94	92.6	64.3	13.39
outlet direction	4	2.73	92.4	64.1	6.86
inlet shape	4	2.68	92.1	63.8	6.64
reduce impeller length	4	1.63	88.3	60.2	3.66
reduce impeller height	4	2.79	92.4	64.1	9.71

4.2 Dynamic analysis results

Results of excitation force measurements are shown in Figure 5(a). Based on the results, dynamic analysis was conducted which show that it is best to locate the mount position at the same horizontal plane as the center of gravity. Also floor transmission force may be minimized by rotating the pump motor 90 degrees from the current setup. Based on these optimization results, optimal shape and location is shown in Table 2.

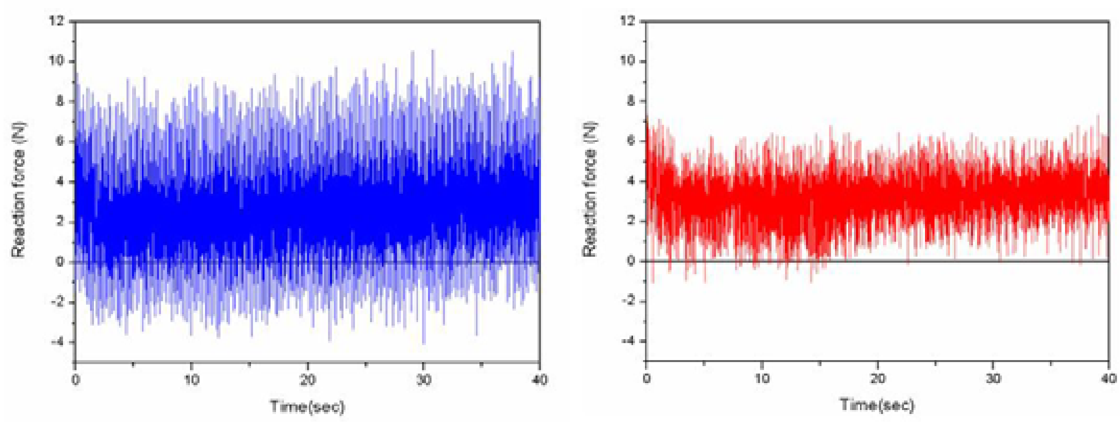
However, the optimal position and shape are impossible to apply in current production washing machines due to restrictions on its size, assembly, spatial, cost, location of other parts, and etc. Adjustments were made on the critical parameters A, B, C, and D to allow implementation and results are shown in Table 2. The new shape shows that it has higher floor transmission forces by still has significant improvement over current production shape.

Table 2 Dynamic analysis results

	variable(mm)				reaction force (N)		Peak-Peak (N)
	A	B	C	D	MIN	MAX	
original shape					-2.35	10.00	12.35
optimized shape	44	140	140	140	-0.86	0.44	1.30
new shape	50	100	100	98.9	-2.13	2.41	4.54

4.3 Comparison between original and new shape on reaction forces

Based on computational analysis and actual experiment results, optimal drain pump mounting shape is obtained. The effect is verified using actual mock up to compare current production sample and optimal design mock up. Comparison of floor transmission force results of current production and new shape results are shown in Figure 5. Table 3 shows summary of experimental floor transmission force results of current production shape (14.95N) and new shape (8.5N). The new shape had 43.14% improvement in reducing the floor transmission force.



(a) original shape **(b) new shape**

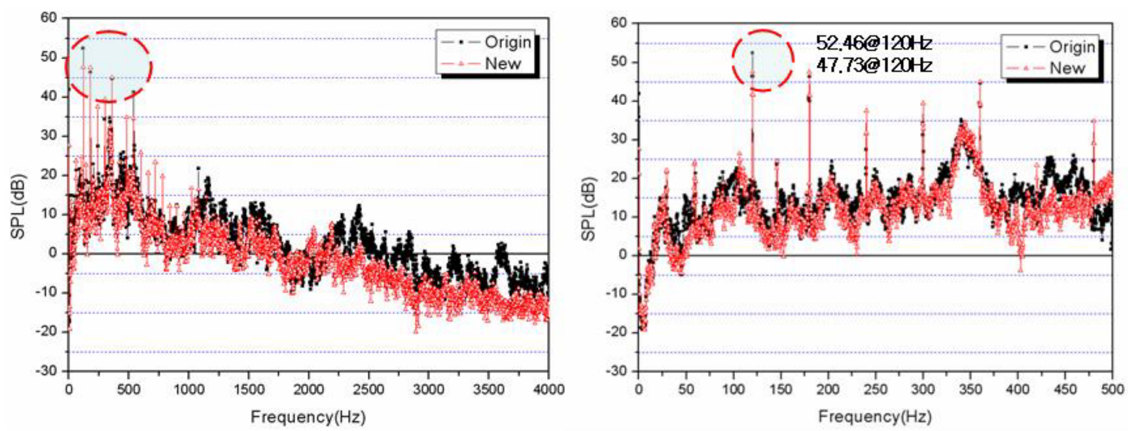
Figure 5. Reaction force comparison between original and new shape.

Table 3 Summary of experiment and analysis results

		reaction force (N)		Peak-Peak (N)
		MIN	MAX	
analysis results	original shape	-2.35	10.00	12.35
	new shape	-2.13	2.41	4.54
experimental results	original shape	-4.81	10.14	14.95
	new shape	-1.53	6.97	8.50
improvement rate (%)				43.14

4.4 Comparison between original and new shape on noise

Figure 6 shows the noise measurement results to verify effect of the new shape in reducing noise. There was 1.84dBA reduction in overall noise level throughout entire frequency range. Significant reduction was found in 120Hz, 2nd harmonic frequency of 60Hz pump motor, where sound level decreased from 52.46dBA to 47.73dBA. It is presumed that 120Hz is air-borne noise from the motor. Summary of integrated sound pressure level is shown in Table 4.



(a) original shape **(b) new shape**

Figure 6. Noise comparison between original and new shape.

Table 4 Integrated sound pressure level

(dBA)

	front	left	right
original shape	46.07	49.25	49.53
new shape	44.29	48.25	46.79

5. CONCLUSIONS

(1) Two simultaneous approaches were taken to minimize the transmission force from drain pump operation. First was to minimize the source of exciting force from water by changing the shape of the impeller and pump case. Second was to reduce the transmission force from the source to elsewhere including the floor and frame.

(2) By conducting parameter study via fluid analysis and noise analysis, results show that changing the number of impeller, height of impeller, length of impeller and exit direction can maintain the pump performance while reducing the noise.

(3) Part level and unit level noise measurement of drain pump system conducted to determine the source of noise. Results show that noise from the current drain pump is contributed largely not from the fluid flow but from the pump itself. Especially the air-borne noise in the 120Hz from motor was critical but improvement in the shape of the drain pump system reduced the sound level by 4.73dBA.

(4) Optimization was performed on the drain pump force transmission route to reduce the excitation force during drain pump operation. Results show that 43.14% floor transmission force was reduced along with decrease of 1.84dBA in sound pressure level.

(5) Redesign of drain pump obtained significant reduction in floor transmission force but relatively less improvement was acquired in reducing noise as motor itself was the dominant source. Therefore, further research will focus to maximize noise reduction effects.

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