Vibration Control in FL Washers using Bottom mount Spring – MR Damper Suspension & Foot-pad

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Abstract— Washing dirty clothes is the most cumbersome of all household chores. To keep up with the fast pace of modern life, washing machines are gradually becoming indispensable, specially for working ladies, bachelors & those having active social life. After the 90s, the horizontal-axis front loading (FL) washing machines have emerged as the more efficient type, gradually replacing the vertical – axis top loading (TL) machines. However, these machines have an inherent severe vibration problem, compelling manufacturers to incorporate costly vibration control measures in their product. This is to a large extent responsible for the FL machines being currently 5 times more expensive than their TL counterparts & higher maintenance cost.

In this paper, a much simpler & cheaper solution is presented, which is capable of reducing vibration to acceptable level with little additional manufacturing & maintenance cost, thereby helping reduce the cost of the FL washing machines to that comparable with TL type, making these more attractive to the customers.

Keywords — Bottom mount Spring-MR damper suspension, counter weight, footpads

Introduction
To help keep pace with the fast pace of modern day life, washing machines have now become a household necessity. The construction & operation aspects of both TL type (common in the US & Asia) & FL type (common in Europe) are discussed below [1]:

TL washing machines (fig 1) :- Clothes are loaded from the top into the red inner drum having perforations on its side wall. Water (hot & cold) flows into the blue outer stationary drum. After adding detergent, the green impeller / agitator, also mounted on the common vertical axis, is made to rotate / swirl in alternate directions during the wash cycle, by the black electric motor with help of v-belt. After some time, the dirty water is drained out with help of the brown pump, fresh water is added & the wash cycle is repeated a certain number of times to ensure that the suds are completely removed. In the subsequent spin dry cycle, the inner drum is made to rotate at a higher speed to extract water by centrifugal action.

Fig. 1 : Schematic front view representation of TL type washing machines

FL washing machines (fig 2) :- Clothes are loaded from the front side into the red inner drum having perforations on its side wall & mounted on a horizontal axis. Water (hot & cold) flows into the concentrically mounted blue outer stationary drum, via a tray containing detergent at the top. A red rubber pad (item 6) is attached to the lower inner surface of the front end of the outer drum to maintain the gap between the 2 drums. A gasket seal is placed between the front door & the stationary outer drum to prevent water spillage & flexible bellow is placed in between the front end of the inner drum & door to prevent clothes from getting trapped in between the 2 drums. The inner drum is rotated by the black electric motor with help of the yellow v-belt. The inner surface of the inner drum has some small black projections parallel to the horizontal axis for better tumbling of clothes in soap solution & more efficient washing.

Fig. 2 : Schematic front view representation of FL type washing machines.

The initial soak cycle is meant to uniformly wet the clothes in soap solution. There after the wash cycle is
initiated for proper rinsing to ensure efficient dirt removal. After some time, the dirty water is drained out from the bottom with help of the brown pump, fresh water is added & the wash cycle is repeated a certain number of times to ensure complete removal of the soapy suds. In the subsequent spin dry cycle, the inner drum is made to rotate at a higher speed to extract water by centrifugal action. [1]

Compared to TL washers, FL machines consume about 60% less water & power, delivers cleaner & dryer clothes, can take larger wash loads & are much more gentler on clothes. However, these machines have severe vibration problems & are about 3 times more noisy. The extent of this problem is highlighted in Fig. 3 obtained from “The Washer & Dryer Buying Guide 2010”. [2-6].

Fig. 3: Comparative study on vibration & noise in different FL washers.

The vibrations, being in the vertical plane, can cause structural damage to the floor & on uneven floors can cause perambulatory oscillatory walk. Incorporating costly vibration control solutions in the product has contributed greatly in making the product price 5 times more expensive & also increasing their maintenance cost, which is a serious deterrent to the prospective customer.

Vibration measures adopted by different makes of washing machines have a common feature: a spring – damper suspension system, shown in green (item 2 of fig.2). This typically comprises of 2 to 4 springs attached to the top & 2 to 4 dampers attached to the bottom surface of the outer drum commonly known as the hybrid mount suspension configuration (fig. 4). [6]

Fig. 4: Hybrid mount suspension of FL washing machine.

In this paper we have proposed a simple vibration control system which is capable of reducing vibration to acceptable limits without substantial increase in product cost. The proposed solution involves a bottom mounted spring – Magneto Rheological (MR) damper suspension along with counter weight & foot pads.

A self-developed program in Matlab is used to solve the mathematical model for 1 d.o.f. spring-damper system under forced vibration, to evaluate the amplitude of vibration. This being inversely proportional to the effectiveness of the system, is a simple & practical means of ascertaining the same.

Applying the concept of Random search optimization technique, by repeatedly changing the design parameters with different feasible values, a near optimal solution, limiting the amplitude of vibration to about 0.5 mm at all the different drum speeds, has been obtained. The adverse effects of this residual high frequency vibration are to be minimized to within acceptable limits using foot-pads. [7]

**LITERATURE REVIEW**

To address the vibration problem, manufacturers have come up with various innovative & patented vibration control solutions, which are effective in varying degrees & also costly to incorporate in the product. This has resulted in a substantial increase in product price & maintenance cost. Some of these are discussed below:-

In the inertial ball balance ring vibration control system, there are 2 concentric tracks containing several steel balls suspended in a viscous fluid at the front & rear end of the inner drum. During drum rotation, the balls were expected to position themselves opposite to the imbalance in wash load nullifying the exciting force causing the vibration & were successful in reducing vibration by 30%. Another system employs inertia sensors / accelerometers to sense excess vibration & subsequently alters the spin speed to allow the wash load to redistribute itself, thereby reducing the wash load imbalance causing vibration. Samsung has incorporated patented Vibration Reduction Technology (VRT) in its products. GE has incorporated patented Adaptive Vibration Control (AVC) in its latest Profile series products, which adapt to changing load imbalances & spin patterns. These use heavy-duty springs, vibration dampeners and a balance ring to help offset the washer if it gets off balance while in use. STACIS® has developed & patented Active Piezoelectric Vibration Cancellation Systems. Maytag Neptune MAH8700 front loading washers have a built-in high-tech vibration reduction system including spring mounted weights that vibrate in reverse to the washer's vibration and a vibration detection system that stops.
the spin and attempts to readjust the load or slow the maximum speed of a spin if it can’t compensate any other way. Of course these developments are the outcome of the hard work by several researchers in the field. While adding significantly to the product manufacturing as well as maintenance costs, the effectiveness of such measures is questionable as evidenced by the fact that the manufacturers themselves advocate the use of accessories like feet-pad [3],[6],[7].

Consumer guides recommend that clothes should be evenly distributed & not tightly packed, to reduce vibration. Many researchers have observed that if the wash load is evenly distributed & loosely packed in the inner drum, then while spinning, the clothes re-distribute themselves to further reduce the vibration causing imbalance. Many researchers have modeled the suspension of FL washers using the simple 1 d.o.f. spring - damper forced vibration system [8]. Use of MR damper in FL washing machine has been advocated by several researchers [6],[7],[9].

Fig. 5 : Schematic diagram of Spring – MR damper hybrid mount suspension

Washing machine manufacturers recommend that accessories like foot – pads be used. Foot – pad manufacturers claim that their product can effectively reduce vibration [3],[6],[7],[10]. We have incorporated these concepts in our work.

**OUR VIBRATION SOLUTION**

Our proposed vibration solution is for a 7 kg. capacity FL washing machine having an inner drum radius of 0.2 m. We have assumed that it is loosely packed with 5 kg of evenly distributed wash load. This is to ensure that the clothes re-orient themselves during the soak cycle to reduce the unbalanced wash load to 0.3 kg at an eccentricity of 0.15 m.

We have used a self developed program in Matlab ver.7.6.0.324 (R2008a) to calculate the amplitude of vibration based on the mathematical model for 1 d.o.f. spring – damper system under forced vibration.

**Table 1 : System data at different operating modes**

<table>
<thead>
<tr>
<th>System data</th>
<th>Soak</th>
<th>MR Damper</th>
<th>Wash</th>
<th>Dry</th>
</tr>
</thead>
<tbody>
<tr>
<td>N rpm</td>
<td>40</td>
<td>50</td>
<td>360</td>
<td>400</td>
</tr>
<tr>
<td>ω rad/s</td>
<td>4.2</td>
<td>5.2</td>
<td>18</td>
<td>42</td>
</tr>
<tr>
<td>k N/m</td>
<td>10k</td>
<td>10k</td>
<td>10k</td>
<td>10k</td>
</tr>
<tr>
<td>c N/m/s</td>
<td>20</td>
<td>1350</td>
<td>1350</td>
<td>20</td>
</tr>
<tr>
<td>ωn rad/s</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>r = ωt/ωn</td>
<td>0.4</td>
<td>0.5</td>
<td>3.6</td>
<td>4.0</td>
</tr>
<tr>
<td>ξ</td>
<td>0.01</td>
<td>0.71</td>
<td>0.71</td>
<td>0.01</td>
</tr>
<tr>
<td>A mm</td>
<td>0.09</td>
<td>0.12</td>
<td>0.50</td>
<td>0.53</td>
</tr>
</tbody>
</table>

Based on our above findings [7], we can describe our vibration control solution for the above specified washer as comprising of the following components:

**Electric motor** – This is placed in the rear & is directly coupled to the inner drum. This arrangement eliminates transmission losses as well as noise & additional cost arising from the use of conventional V-belt / gear train. It is fitted with a 3 – speed regulator: 40 rpm in soak mode, 400 rpm in rinse mode & 1200 rpm in dry mode. A speed sensor with microprocessor is required to activate the MR damper in the inner drum speed range of 50 – 360 rpm.

**Counter-weight** – a ring shaped concrete slab is mounted (fig. 7) on the front end of the outer drum to lower the natural frequency of the system. It also helps to counterbalance the weight of the electric motor. The weight of the counterweight is such that the total machine weight is 75 kg. Concrete slab of specified weight & shape is easy as well as cheap to manufacture.

**Spring** – 2 to 4 nos. may be attached to the bottom of the outer drum, having total effective stiffness of 10 KN / m. It may be incorporated within the MR damper (fig. 7) or separately.

**Magneto - Rheological ( MR ) damper** – These are dashpot type dampers, but containing MR fluid ie. micro / nano sized metal particles suspended in fluid of low viscosity (fig. 7). 2 to 4 nos., may be attached to the bottom of the outer drum & connected to the microprocessor circuit [6].

**Fig. 6 : Displacement Vs Time in Dry mode @ 1200 rpm**

Using the concept of random optimization technique, we have repeatedly changed the system parameters with the objective of minimizing vibration amplitude & obtained a near optimal solution. We have observed that the spring – MR damper suspension system is theoretically capable of reducing the amplitude of vibration to about 0.5 mm or less at all operating speeds (fig. 6, tab.1).
During the soak / rinse / dry mode, when the dampers are in the de-activated condition, these have effective damping coefficient of 20 N/m/s, providing a negligible damping factor of 0.011. However, when switching to rinse / dry mode, as the inner drum rotational speed approaches & passes through that corresponding to the system’s natural i.e. resonance frequency, the damper is activated by an electro-magnetic field. This causes the metal particles to align themselves along the magnetic flux, effectively increasing the fluid viscosity & the effective damping coefficient increases to 1350 N/m/s, providing a damping factor of 0.712. The cost of MR damper is 2–3 times that of a conventional hydraulic damper. [7]

These foot – pads are fairly easy to install. First lift each corner of the machine and slip a pad under each foot. Mark each pad location on the floor. Then lift the washer out of the way. Clean the floor under the pads. Then stick the adhesive discs to the floor. Apply the primer to the bottom of the pads and press them onto the discs. Lift the washer back into place, locating the feet in the pad recesses. [10]

Most of these foot – pads use elastomer materials eg. cork, felt, rubber, neoprene, silicone, etc. Water Resistant Sorbothane®, a proprietary, visco-elastic polymer (thermoset, polyether-based, polyurethane material) having an excellent combination of shock absorption, vibration isolation & vibration damping characteristics, coupled with a long fatigue life & a favorable operating temperature range of -29° to 72° Celsius is an excellent material, successfully being used in space station applications. Anti-Walk Silent Feet anti-vibration washer pads uses this material & are considered to be most effective though marginally costly. [11]

CONCLUSION
As per our findings, the near-optimal vibration solution described above can be incorporated in a washing machine with comparatively very little increase in product manufacturing & maintenance cost while being reasonably effective in reducing vibration to acceptable level.

Scope for further work includes obtaining the abovementioned components, fabricating a decent prototype & conducting vibration tests thereon to validate our findings & also help develop a more effective design.

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A wide variety of foot – pads are readily available in the market (fig. 8).

We recommend that the spring – MR damper suspension be set up in the bottom mounted configuration (fig. 7). By doing so, the side panels are not subjected to noisy vibration. Also the side panels need not be robust (thereby reducing manufacturing cost). [6]
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