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Research Article

Design and Development of Vertical Axis Washing Machine Suspension System for Stability

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Abstract

The working process of a vertical axis automatic washing machine is divided into three Successive steps: washing, rinsing and spin-drying. An automatic washing machine undergoes rotational unbalance due to unbalanced mass during the spinning process. The imbalance may cause serious vibrations in the third step while ramping up to high speed. A liquid balancer assembly and suspension system plays a vital role in controlling this unbalance. In spin cycle, tub hit the cabinet and creates the objectionable noise the main parameters include rotational speed, eccentricities of the center of rotation, hydraulic force (restoration force), and Degree of Freedom. This paper includes Design and Development of a new suspension system with the help of CREO and Analysis tool ADAMS of vertical axis washer. Simulation performed on washing machine during spin-drying mode, and results will be compared with existing data.

Keywords: Washing machine; Unbalance load; Numerical simulation

Introduction

A washing machine is very complicated system with combination of dynamics and electronics control system where valve, motor control on the base of sensor information such as load, tub motion. washing machine is classified into two categories Top loading washing machine (Vertical axis washer) and Front-loading Washing machine (Horizontal axis washer). Top loading washing machine has four suspension rod through which wash unit is suspended. Wash unit have one non-rotating tub and inside tub one rotating basket. Nowadays, the industrial focus is on increasing capacity of a washer, low vibration, and noise. So, these areas getting more attention and have been actively studied. The objectionable effect of washer working is vibration and noise. so, research into damping of washing machine vibration is widely conducted. Step of washing machine are: washing, rinsing, and spin-drying. In the third step, unbalance may be created in the basket if clothes clump together.

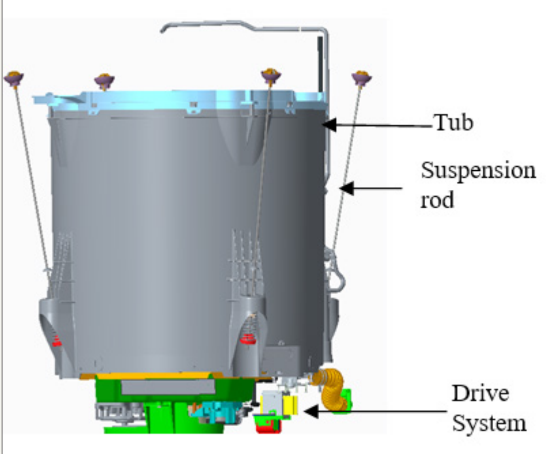

Figure 1: Existing washing machine.

Due to a high rotation speed of the basket, the imbalance may cause serious vibrations in the spin-drying process. This raises the vibration problem to become gradually grave. Actually, in vertical axis washer load is not uniformly distributed that why the centre of mass does not usually lie on the axis of symmetry of basket. So, basket rotates about an axis other than the axis of symmetry and causes eccentric motion (Figure 1). A vertical automatic washing machine of Impeller -type the spin-drying process, a hydraulic balancer ring is used for vibration control. It is partially filled with water and attached at the upper part of the rotating basket. At the steady state of the spin cycle, if the rotation speed of the basket is high enough, the liquid in the balancing ring will redistribute and shift to the opposite side of the imbalance load under the effect of the centrifugal forces, thus reducing excessive vibrations of the washing machine.

Peter & Bauer [1] patented a friction damper suspension of washing machines. The friction piston is provided with friction elements (foam) pressed elastically against the inner wall of the housing, to attain a considerable reduction in the damping forces once there has been a passage through the unbalance range, the housing is made of plastic. Chen [2] analyzes Hopf bifurcation is a critical point where a system's stability switches and a periodic solution arises. Parameters affecting the hopf bifurcation including the rotational speed, mass of the clothes radius of gyration, axial damping coefficient and spring stiffness were considered.

Choi [3] and Seok [4] develop a dynamic model to study the nature of balance ring. Dewater the clothe is critical process in spin cycle. so, formulate a problem of design optimization that minimize the maximum deflection of tub at low rpm speed. Using proposed design approach, optimal value of the maximum displacement at low-speed spin cycle was reduced by 13.1%, compared to the initial value, while satisfying the design constraint on maximum displacement of a high-speed spin cycle. Jang [5] established the multibody dynamic model by obtaining the data of several complements through experiment on MTS test machine. experiment was performed using the waterproof cloth that dehydrate the clothe immediately in spin cycle and analyze the effect on washing machine in spin cycle to study the unbalance nature of washer.

Dehydration of clothes in spin-cycle create the objectionable vibration and noise due to non-uniform distribution of clothes. In unbalance conditions, tub hit the cabinet and transfer the vibration to cabinet. In this paper, Multibody dynamic simulation carried out in order to study the deflection of tub and forces on rod. Also, focus on stability of washing machine during dehydration process.

Kinematics of Vertical Axis Automatic Washing Machine

Vertical axis washing machine depends upon the suspension system use such that wash unit of a machine can be suspended from top four corner of cabinet enclosure. In spin cycle, the washing machine has to continue ramping up higher spin speed with increasing larger capacity wash unit so dynamic forces of a washing machine at low and high speed are critical to managing. The standard architecture of modern vertical axis washing machines incorporates a hung mass design, where a wash unit is suspended from a cabinet structure through the use of suspension strut assemblies. This architectural approach is a deviation away from the traditional old standard of suspending and supporting a wash unit from a pedestal base on the lower ground surface. Hung suspension architecture allows numerous changes to be made for the hopeful advantage of the system. In order to convert from a pedestal base to a hung mass system, numerous components must be changed. The wash tub has to become stiffer in order to be suspended from the cabinet suspension gusset and socket features to interface suspension assemblies to the tub. These frames and their attachments have to be structural enough to support the static weight (of a fully water loaded wash unit) and dynamic forces of the hung mass. The cabinet wrapper itself has to be stiff to support the dynamic forces and vibration since the cabinet must now bear and support the weight of the hung mass. So, the thickness of wrapper is sufficient to strengthen the structure and forces.

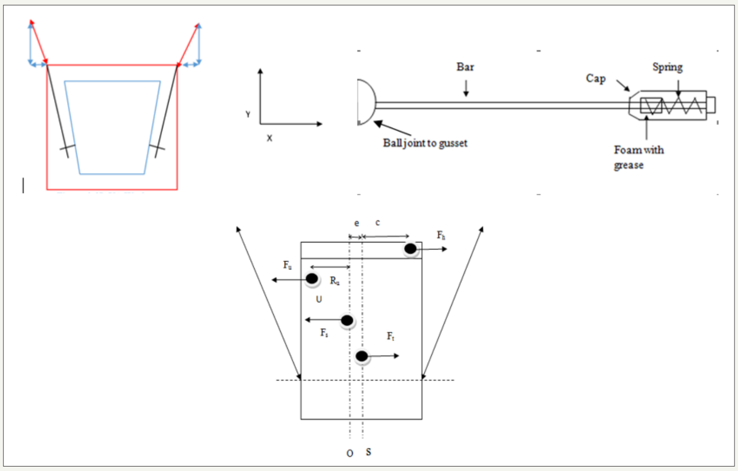

Figure 2: Free body diagram of force in washing machine from tub to cabinet through suspension rod.

The hung suspension architecture provides a well-matched and balanced dynamic for carrying unbalance versus the typical profile of generated unbalance in machine. From basic mechanics, we can decompose that red suspension force into 'x' and 'y' force components, as illustrated by the light blue arrows. As the 'x' component of suspension force becomes increasingly less, physics dictates that the cabinet vibration would decrease as well (Figure 2).

VA washing machines typically have two dynamic natural frequencies:

A. A pendulum mode of the wash unit, where it swings and pivots out in a radial direction between the speeds of 50-100rpm. In this tub strikes the cabinet and create objectionable noise.

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B. Rocking type event, where between 175-225rpm the wash unit will jounce up and down vertically, and sometimes causing significant suspension travel.

In spring and damper assembly, foam with grease frictional phenomena uses to manage unbalance during the mid-speed spin frequency. The foam and grease damper produce coulomb damping force through the generation of friction due to contact of the foam against the rod. The foam is placed in compress position, so foam displaced axially along the length of rod. This sliding motion creates frictional interaction between foam and rod and converts mechanical energy into thermal energy. This foam absorbs and dissipate heat and grease provide lubrication.

The amount of damping force that is produced by the suspension system is dependent upon a number of factors:

1. Diameter of the rod component
2. Surface finish and material (friction)
3. Density (modulus) of the foam
4. Amount of total compression of the foam against the rod
5. Height/length of the foam
6. Lubrication effects of the grease, and the grease temperature during operation

As the suspension sockets moved up on the tub and the suspension rods had an increasingly horizontal angle, it obvious that more cabinet vibration occurs. So, we have to focus more on horizontal component of suspension to manage the unbalance in a washing machine during the spin cycle. To manage the unbalance concept created.

Force transmission and eccentricity of tub

Force transfer from basket by following components as per the order

1. Upper bearing
2. Lower bearing
3. Suspension rods
4. Balance ring force
5. cabinet
6. feet

Source of force generation in wash unit

Unbalance mass centrifugal force $Fu = mu\ ru\ \omega^2$

Restoring force supporting structure $Fs = k\ e$

centrifugal force supporting shaft $Ft = M\ e\ \omega^2$

Force of balance ring $Fh = \rho\ h\ \pi\ R^2\ \omega^2$

Where,

Ru = Gyration radius

mu = Mass of the imbalance

e = Eccentricity of the whole system

ω = The rotation speed at the steady state

M = Mass of the supporting structure

k = Stiffness of the supporting shaft

c = Distance of the centroid of liquid C from the symmetric center S.

$$F_u + F_S = F_t + F_h \quad (1)$$

$$m_u r_u \omega^2 + ke = Me\omega^2 + \rho h \pi R_o^2 \omega^2$$

Eccentricity of tub

$$e = (m_u r_u \omega^2) / (M\omega^2 + \rho h \pi R_0^2 \omega^2) - k) \quad (2)$$

Deflection of Tub

$$y = (\omega / \omega_n)^2 * e / 1 - (\omega / \omega_n)^2 \quad (3)$$

Total Deflection of tub= Eccentricity + Deflection = $e + y$ (4)

Unbalance load is placed at three different locations in tub to test the washer for its stability during spin cycle. Due to ball joint at both end of suspension rod, wash unit try to regain its original position once its deviate from its original position. Driving shaft, basket is attached in such manner that it will maintain its linearity. Force in balance ring is opposite to the unbalance load.

Arrangements for Stability of Tub

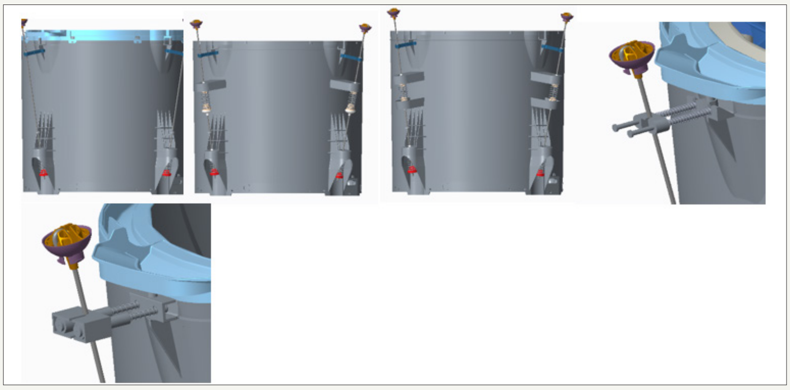

Figure 3: (i) Existing system (ii) concept 1 (iii) concept 2 (iv) concept 3 (v) concept 4.

To take care of the issue of unbalance, diverse ideas are created. These ideas are for the most part in view of the change of suspension framework. First, two concepts are based on the modification of tub geometry and using same spring-damper suspension assembly. These concepts double housing suspension system reduce its swing and jouncing effect during ramping up and reduce the number of hit between cabinet wall and tub (Figure 3).

Concept 3 and concept 4 are external suspension assembly will be attached at top of tub whose one end will attached to tub and another to rod. Concept 3 is based of friction damping and concept 4 is based on air damping (Figure 4). The concept selection matrix helps to select which concept is better than others. It is a scoring matrix used for concept selection in which various design parameters scores is a criterion for better concept. The selection is made based on the consolidated scores.

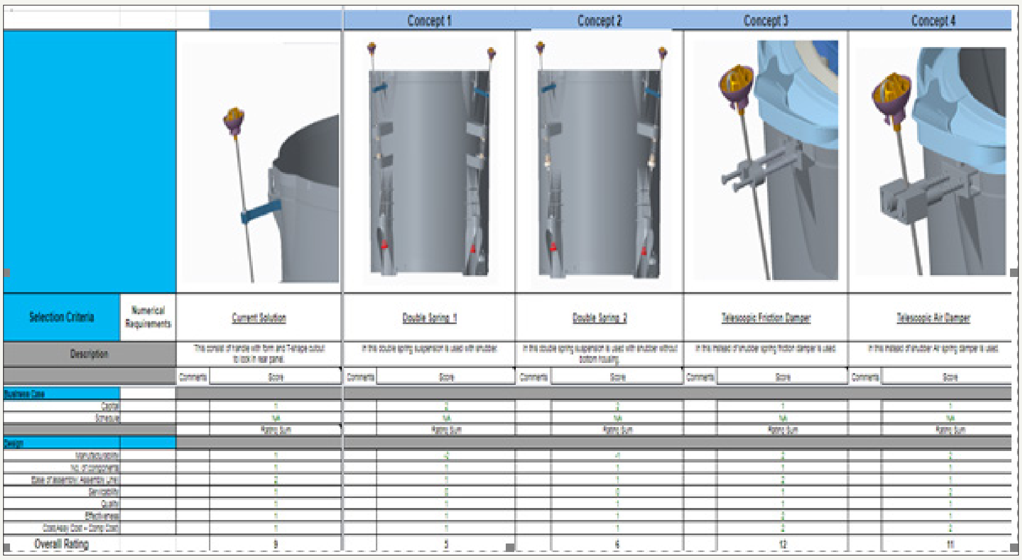

Figure 4: Concepts selection matrix.

Parameter to finalize concept

1. Concept selection matrix rating
2. Less number of Component
3. Cost estimate
4. Effectiveness

From above parameter, concept 3 is selected (Figure 5)

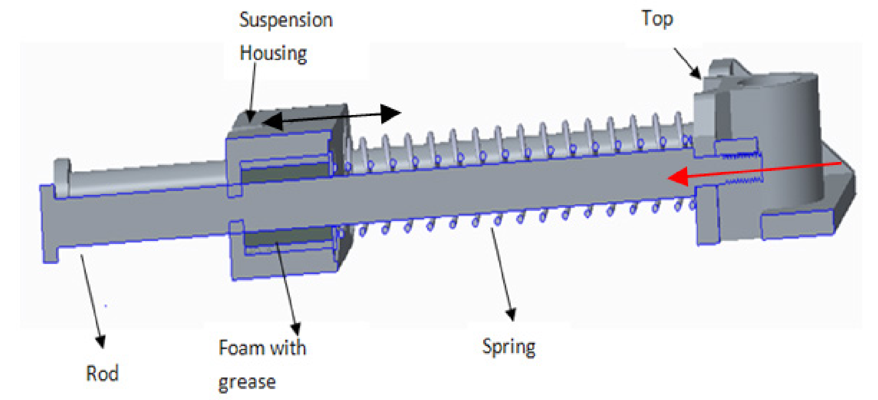

Figure 5: Concept 3 component.

Working Principle of Telescopic friction damper suspension

1. Foam is Provided in Tele-scope Housing
2. It will Act Like Friction damper.
3. When compressible force is applied piston rod move along axial direction (red arrow). So, it provides friction between rod and foam with grease. It converts motion energy into heat energy and damp the vibration.

Analytical Calculation, Numerical Simulation and Experimental

Analytical representation

In spin cycle unbalance occur so as to validate proposed concept mathematical calculation performed. As per the standard, unbalance is check at 1.5kg placed at the inner top of the basket(phase-in). The gap between tub and cabinet wall is 25mm and deflection of tub is more than 25mm that's why tub hit the cabinet (Figure 6).

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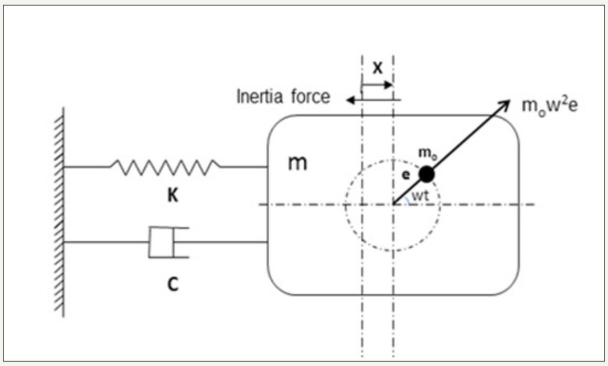

Figure 6: Free body diagram of washing machine drum.

To find the damping factor, we have to find viscous damping coefficient of coulomb friction.

Here coulomb frictional force between foam with grease and rod

$$F_r = \mu * F \quad (1)$$

The resistance force, F_r, in the case of Coulomb friction dissipates $W_c = 4 * F_r X$ in energy over each quarter cycle as shown in Figure 7, hence, equating the total dissipative work per cycle to that done by a viscous damper, we have

$$W_c = 4F_r X = \pi C \omega X^2 \quad (2)$$

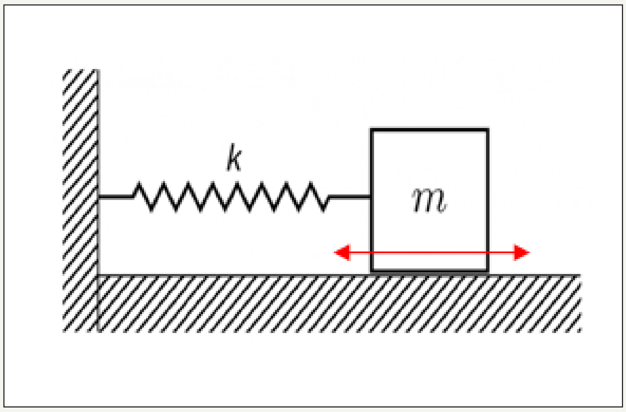

Figure 7: Spring mass system.

The gap between tub and wall is 25mm so the total travel of suspension housing not more than 23mm else tub hit the cabinet.

Now the coefficient of damping

$$\xi = \frac{C}{2m\omega_{n1}} \quad (3)$$

Deflection of tub is

$$X = \frac{m_o e \omega^2 / k}{\sqrt{\left[1 - \left(\frac{\omega}{\omega_n}\right)^2\right]^2 + \left[2\xi \frac{\omega}{\omega_n}\right]^2}} \quad (4)$$

Nomenclature:-

m_o = Unbalance mass, kg

e = Eccentricity, mm

ω = operating speed, rps

k = spring stiffness N/mm

ω_n = Natural frequency of washer, rpm

ω_{n1} = Natural frequency of suspension, rpm

F_r = Friction force, N

μ = coefficient of friction

ξ = damping ratio

c= coefficient of damping, N-s/m

W_c = Energy dissipation, J

from equation (4), using Stiffness (2250 N/m) shows 35.48% reduction in deflection from the conventional suspension system by analytical.

Numerical Simulation

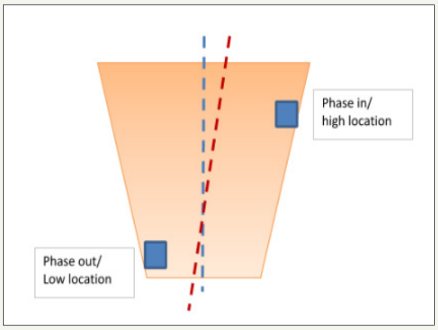

Figure 8: Location of unbalance.

Washing machine is multi-body dynamics which contain suspension system rotary system, hung supports, base, balance ring etc. Simulation is performed by Adams. Displacements versus time plots are obtained as an output. ADAMS simulation is run for 30sec with the time step of 0.01sec. Simulation is performed by considering different stiffness of spring and new result is compared with existing system. The unbalance load 1.5kg is considered at top of basket called as Phase in location (Figure 8).

Adams Result Comparison between Conventional and Proposed Suspension Deflection. Simulation is also performed by using different spring stiffness to check the behaviour of suspension.

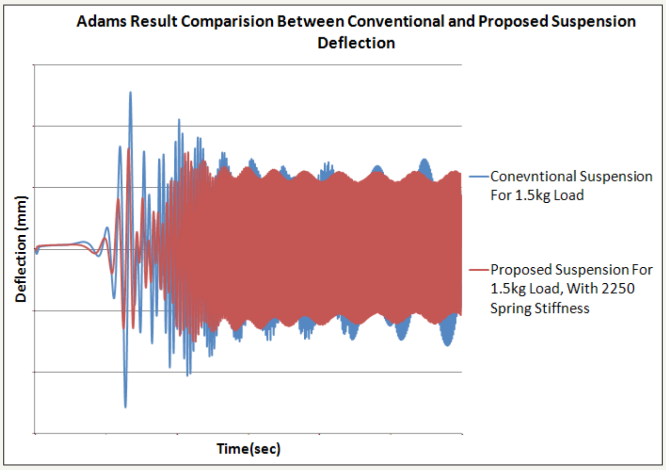

Figure 9: Time vs. Deflection for 2250N/m.

A. Case 1: Deflection of tub using unbalance load 1.5kg for spring stiffness-2250 N\m (Figure 9).

B. Case 2: Deflection of tub using unbalance load 1.5kg for spring stiffness-1150 N\m (Figure 10).

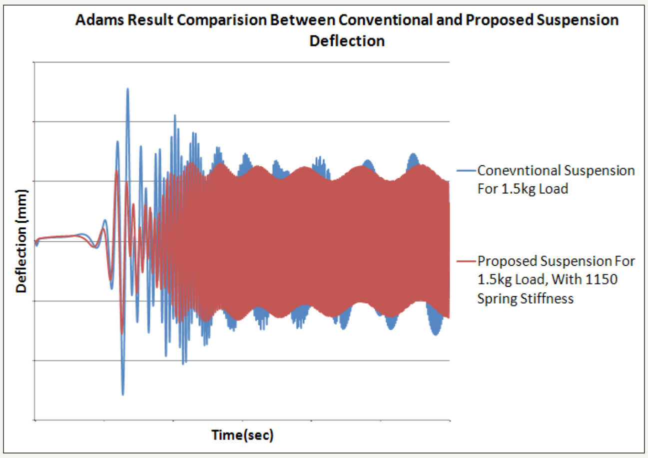

Figure 10: Time vs. Deflection for 1150 N/m.

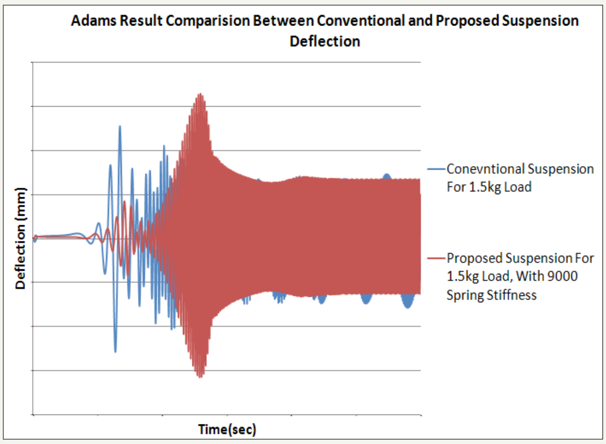

Figure 11: Time vs. Deflection for 9000N/m.

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C. Case 3: Deflection of tub using unbalance load 1.5kg for spring stiffness-9000 N\m (Figure 11).

Experimental analysis of vertical axis washing machine tub

In order to check the number of hit between tub and cabinet testing is executing a system in order to identify any gap, error or missing requirement in contrary to actual requirement. Experimentation performed at 1.5kg of unbalance load at top position in basket. Run time of test model was 30sec and check the number of hit between cabinet and tub. The prototype of auxiliary suspension system and block diagram of experimental set up is mention in this section (Figure 12-15).

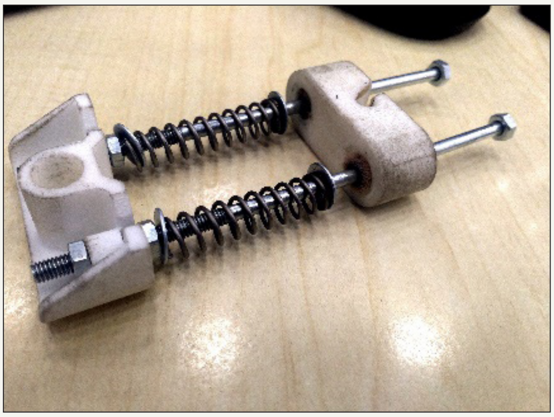

Figure 12: Prototype.

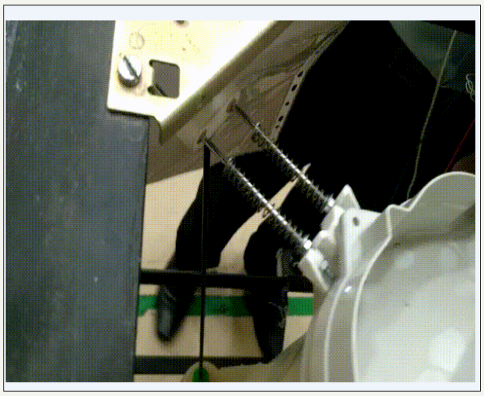

Figure 13: Location of assembly.

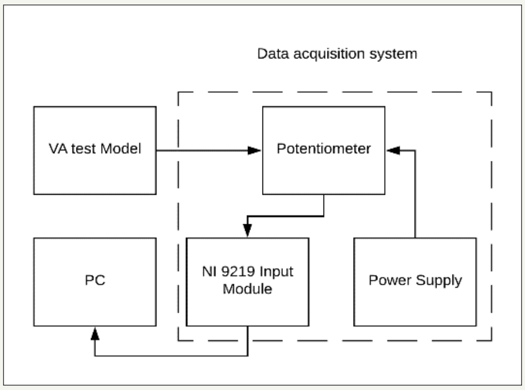

Figure 14: Block diagram of experimental set up.

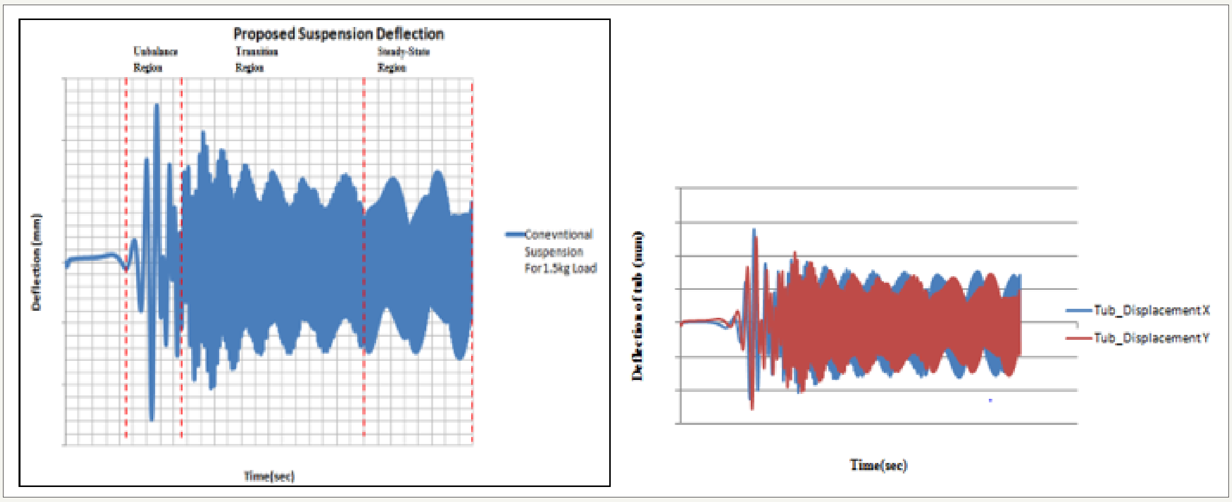

Figure 15: Tub deflection result for 1.5kg unbalance load in washer in X and Y direction.

Results Correlation

Stiffness of 2250N/m is selected on account of following reason:

A. Minimum and maximum wire diameter

B. Minimum number of active coils

C. Maximum working strength

D. Available free length

E. Spring force at working length and permissible variation

Comparison of result in the form of percentage of reduction in deflection of tub between existing and propose concept.

The % reduction in deflection of tub is as follows

$$\%\ error = \frac{Existing\ deflection - proposed\ concept\ deflection}{Existing\ deflection} * 100 \quad (5)$$

Case 1 stiffness (2250 N/m) shows 22% reduction in deflection from the conventional suspension system using auxiliary suspension assembly (Table 1).

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Table 1: Comparison of % reduction in deflection of tub in rrror.

Sr. No.	% Reduction in Deflection of Tub
	1.5kg loading load
Analytical	35.48
simulation	36.61
Experimental	22.58

Conclusion

In this paper, the analytical formulations of a suspension system as well as simulation of a vertical axis washing machine are presented with prototype testing of proposed concept. From a whirling model of a washing machine, the deflection of tub is calculated from the eccentricity and unbalance mass. comparing the simulation with the analytical, the mathematical model presented in this paper shows good agreement with the actual behaviour of the washing machine and control the deflection of tub. Force transmission from tub to suspension rod is within limits, so it cannot bend the rod and not transfer the vibration to cabinet.

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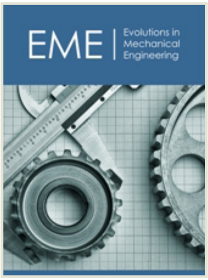

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