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Optimization of a Drum Type Washing Machine By Analytical and Computational Assessment

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Abstract— Eco Efficient systems are the need of the hour in the market. This paper proposes an idea for the optimization of a washing machine in terms of reduction in drum vibration, power consumption and water consumption. The complete model of the washing machine is modeled in Solid-Works 2010 and its modified model in terms of eco-efficiency with respect to water consumption is proposed in this research. Also in this research, a mathematical model is formulated for reducing the drum vibration and an improved drum design is proposed to further reduce the vibrations. Based on the values obtained from the mathematical model, the Finite Element Anlaysis of the old and the new model is performed in Solid-Works Cosmos software and it is observed that the drum displacement reduced to a considerable extent in the new model. By replacing the electromechanically controlled motor by a three phase induction motor, the power consumption (mainly speed, torque and power) is also reduced. Thus in nutshell, the water consumption, drum vibration and the power consumption is reduced which led to an overall optimization of the washing machine.

Index Terms— Optimization, Finite Element Analysis, Mathematical Model, Drum Vibration, Power Consumption, Water Consumption.

1 Introduction

CURRENT environmental awareness demands the improvement of washer efficiency. Talking about efficiency, the first thought that comes to mind is optimization. The basic factors that lead to optimization in a washing machine are its washing capacity, power consumption, cost and vibration. In terms of power consumption, two third of all electrical energy generated is consumed in industry. The industrial drive technology can be classified into two different groups. One group includes electrically driven machines requiring speed control systems for different applications for example, machine tools and measuring machines for which precision in movement is required. Second group includes consumer electrical systems, for example pumps, washing machines, food processors, vacuum cleaners and fans where precision torque or speed control systems are not needed. Common disadvantages of these systems are poor efficiency and distortion. This has resulted in large energy consumption. High efficiency, reduced noise, extended lifetime, rapid time to market at optimum cost are the challenges faced by many industries which use electric motors. Today, the demand for energy saving is increasing rapidly, not only in the automotive and computer peripherals industries, but also in industrial applications and home appliances such as heating and ventilation systems, power tools, vacuum cleaners and washing machines.All these consumer applications need cost-effective solutions without compromising quality. Sanjay Mohite et al. [3] proposed a design using multimode multiple matrix convertor. In this the output voltage is synthesized by switching the IGBTs (Insulated Gate Biploar Transistor) in a matrix. Switching is done by control signals generated by SPWM (Sinusoidal Pulse Width Modulation) techniques where SPWM technique is used to control desired output voltage across load. Evangelos Papadopoulos et al. [6] modeled a horizontal axis washing machine focusing on portability. An innovative method of minimizing vibrations was proposed i.e an improved estimation of the drum angular position and velocity results in greatly reduced residual vibrations. Finally, it is noted that the passive and active methods of stabilization are not exclusive and therefore, they could be employed in parallel, improving thus the washer`s spinning response. But, the drawback of this technique was that it lead to a drastic increase in the cost of the machine. In the present market scenario, the development of high speed spinning washing machines is a great challenge. In the water extraction process, the drum starts rotation and this gives rise to significant centrifugal imbalance forces and imbalanced rotation of the laundry mass. This results in vibration and shaking. By elimination of such vibrations it will be possible to design more silent washing machines for higher wash loads within the same housing dimensions. Thomas Nygards et al. [4] developed a multibody model of a commercial frontloaded washing machine and performed dynamic analysis (eigen frequencies, eigen modes, force transmission) and kinematic analysis (drum motion) of the washing machine during spinning. They developed the model to make it possible to analyze dynamics and vibration of frontloaded washing machines which can be used to solve several optimization problems for washing machines both with conventional passive suspension as well as with active suspension systems. They developed the model basically to show the feasibility of a two-plane automatic balancing device for vibration reduction. S. Bae et al. [7] performed dynamic anlaysis of an automatic washing machine

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with a hydraulic balancer. They concluded that that the vibration would be reduced by increasing the mass, decreasing the volumetric ratio, and increasing the inner radius of the hydraulic balancer. In order to reduce the vibrations of a washing machine, Seok-Ho Son et al. [8] formulated a design optimization problem that minimized the maximum displacement of the spin component in a low-RPM setting while satisfying the design constraint on the maximum displacement of the spin component in a high-RPM setting. They successfully obtained optimal results using the meta-model based design optimization and performed an additional experiment to verify the validity of the results by installing optimally designed layers. The maximum displacement of the lower RPM was found to decrease about 13.1% compared to its initial value while still satisfying the constraint on the maximum displacement of the higher RPM. Based on the above literatures and also based on the market survey, the optimization of the varioius parameters like water consumption, power consumption and drum vibration were performed to obtain a cost effective solution.

2 Washing Machine

A washing machine of 7 kg capacity was designed in SolidWorks 2010 as shown in figure 1. The specification of the machine were obtained from the user's manual of the machine.

Fig 1. 3D Model of a Washing Machine designed in Solid-Works 2010.

Table 1: Basic Parameters affecting the machine performance

Parameters	Speed	Torque	Power
Value	1400 rpm	17.74 Nm	2.6 KW

A washing machine mainly comprises of a drum and its affecting parameters are its speed, torque and power as shown in Table 1.

3 Optimization

Optimization is a technique of finding an alternative solution with the highest achievable performance under the give constraints, by maxming desired factors and minimzing undesired ones.

3.1 Water Consumption

A part of this reseach focuses to develop a more water efficient washing machine which can reduce the water usage capacity without increasing the energy usage and cost. Having this criteria as the basis, a conceptual flow chart is designed as shown in figure 2.

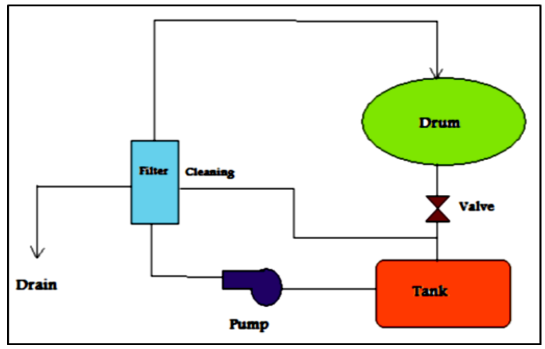

Fig 2. Block Diagram of the Eco-Efficent Washing Machine.

The design criteria of the concept is to save the amount of water, time to complete the washing process, energy required to operate, space required to install the system, cost of the system, Robustness of the system and laundry cleanliness.

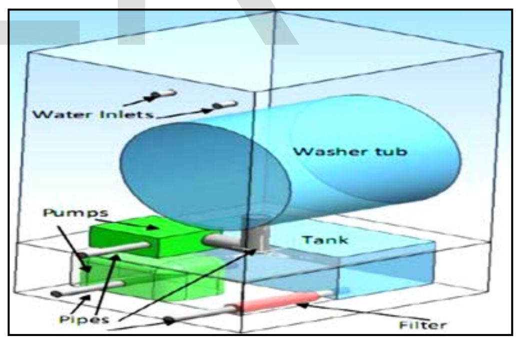

Fig 3. Conceptual Design of an Eco- Efficient Washing Machine.

As shown in figure 2 and 3 a filter and a tank is added to the original washing system. Between each washing cycle, the dirty water from the last cycle initially drains into the tank (valve is open). Then it is pumped through the filter into the tub for use in the next cycle. This process continues till the last cycle. After the final cycle, the pump runs reversely and the water is pumped into the filter (as the valve is closed) and the water then drains out as it leaves the filter. On perfoming analysis, it was found that this new concept saves water consumption upto 75% without increasing the energy consumption and cost; and it also reduces the filtration cycle time and the water is cleaned to the level 6 to 19 nephelometric turbidity units; which is a very Eco-Efficient way to wash clothes.

3.2 Drum Vibration

Most common front loaded washing machines are supported by 4 springs on the top and 2 dampers on the bottom. The simple structural diagram of the whole system is in figure 4.

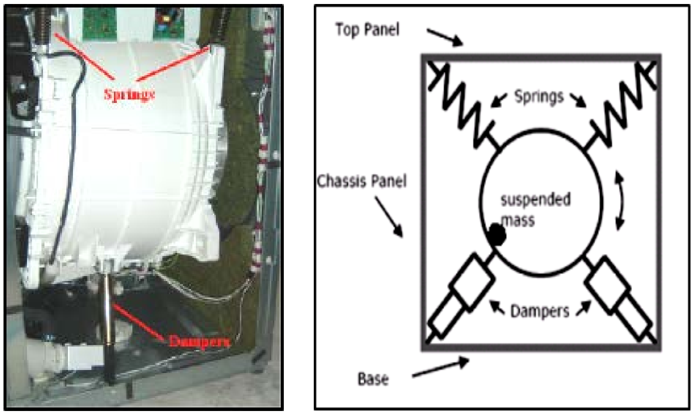

Fig 4. Structural Model of a Washing Machine.

The wet clothing in the washing machine acts as the unbalance weight of the system. While it is rotating at a maximum speed of 1200 rpm, the weight of the clothing causes an angular force (since the weight is not in the center of the machine) which results into vibration. The vibration transfers into the casing and further into the building structure. The springs and dampers minimize the vibration to a certain extent but this research focuses to further reduce the vibrations as much as possible and so the mathematical model is formulated to optimize certain values which influence the vibrations. The above system can be mathematically modeled as a one degree of freedom system consisting of a spring, mass and a damper facing rotational imbalance as shown in figure 5.

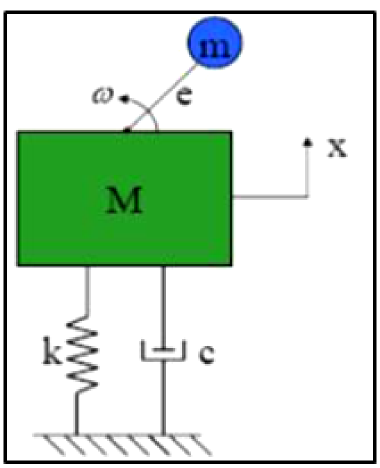

Fig 5. Free Body Diagram of the drum (One DOF).

Using the fundamentals of force balance, we can frame the equation of motion as follows:

$$\sum F_x = (M - m)\,\ddot{x}$$

Where,

M = Total mass of the system.
m = unbalanced mass.
e = eccentricity.

On further simplification we obtain the equation given below;

$$M\ddot{x} + c\dot{x} + kx = me\omega^2 \sin \omega t \ = F_0 \sin \omega t$$

Where,

$$F_0 = \ me\omega^2$$

From the above equation, it is clear that the unbalanced force is due to mainly three factors, mass of the clothes, radius of the drum and rpm of the machine.

To understand the drum displacement better, the above equation was further solved and at the following solution was obtained;

$$X = \frac{mer^2}{M\sqrt{(1-r^2)^2 + \ (2r\zeta)^2}}$$

The above equation mainly consists of two terms that are of closely related to the drum displacement;

$$r = \text{Frequency Ratio} = \ \frac{\omega}{\omega_n}$$

$$\zeta = \text{Damping Ratio} = \frac{c}{c_c}$$

ω and ω_n are influenced by spring stiffness k.
Here, X is the drum displacement and it can be minimized if the values of frequency ratio and the damping ratio can be optimized.
In order to obtain these values, certain constraints were set as shown below;

Weight of Machine = 225 lb (102 kg)
Weight of Wet Clothing = 20 lb (90 kg)
Maximum Rotational Speed, rpm = 1200 rpm

These values were fed into the excel solver and the optimized values that were obtained are as follows:
k = 4000 lb/in for 4 springs = 1000 lb/in for each spring.
ζ = 2
C = 3800 lb/in for 2 dampers = 1900 lb/in for each damper
X = 0.3241 in.

These values were the confirmed as the best suited values on the basis on different literature survey and also on the basis on market survey.Also the previous values of damping ratio ζ was 0.1 and the system was an underdamped system and so it took time to come to a stable position. But after the optimization the best suited value for ζ is 2 and the system becomes an overdamped system and so it gives a minimum drum displacement of 0.3241 inch (8.2321 mm). This vibration was further reduced by modification in the drum design.

3.3 Modified Drum Design

In order to modify the drum design, 13 ball bearings at a distance of 2 inch (50.8 mm) from each other with respect to the diameter were arranged all along the periphery of the drum. The modified drum design is as shown below:

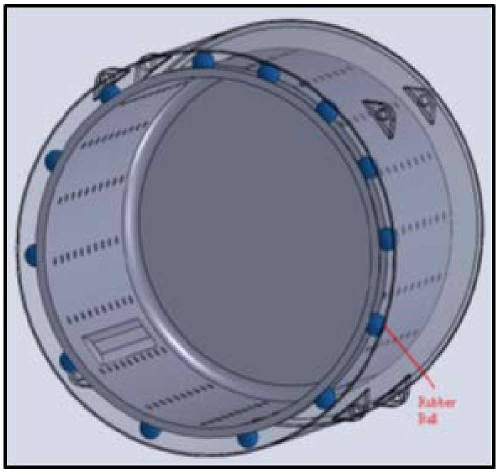

Fig 6. Modified Drum Design

These ball bearings are made of plastic material with a considerable amount of elasticity, and so these bearings act as an additional spring to the drum. Now when the drum is rotating, the unbalanced force generated from the wet clothing is absorbed by these ball bearings first and then the additional vibration will be reduced by the outer springs and the dampers attached to the system. On perfoming the total analysis, it was found that the the drum vibration reduced by 43%.

4 Finite Element Analysis of the Drum

The old drum and the new drum were designed in Solid-Works 2010 and to validate the new design, both the models were subjected to FEA analysis in Solid-Works Cosmos software integrated in Solid-Works 2010.In order to perform the analysis, the following parameters were fed in the software.

1. Rotational arm (backside of the drum) fixed.
2. Force of 98.1 N= (10 kg (weight of clothes) * 9.81 m/s^2).
3. Rotational Speed of 1200 rpm (Optimized value).

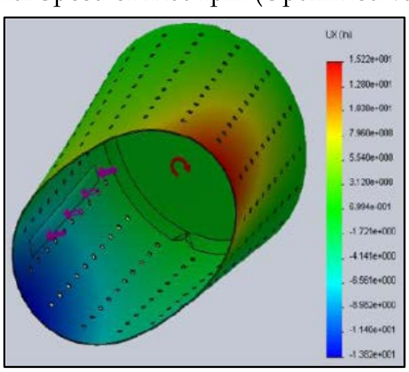

Fig 7. Drum Displacement of the Old Desgin

On performing the analysis on the old design of the drum, the drum displacement was found to be 15.22 inch (386.08mm).

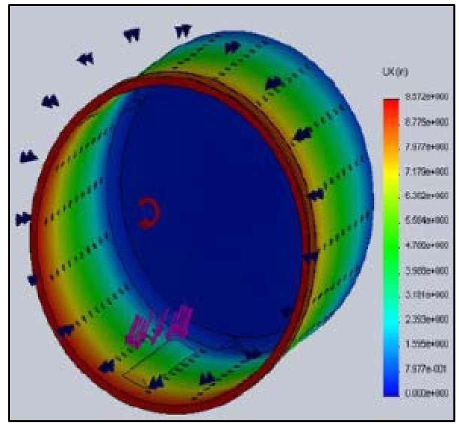

Fig 8. Drum Displacement of the New Desgin

In the new design an additional constraint to the ball bearing was added and the drum displacement was found to be 9.572 inch (243.1288 mm).

5 Conclusion

In order to optimize the performance of a washing machine having a capacity of 7 kg, a design optimization problem was formulated that minimized the maximum displacement of the drum by 43 % in a low-rpm setting of 1200 rpm reduced from 1400 rpm ,while satisfying the basic necessity of washing clothes. Also, a conceptual modified model of the new machine was proposed and it was observed that the water consumption reduced by 75 %. As a part of this research, an electromechanically controlled, two speed, single phase AC-induction motor was replaced by a three phase induction motor which provided a maximum drive performance at a competitive price. With the use of this motor, the power consumption reduced to 2 KW from 2.6 KW and as a result the torque also reduced to 15.96 Nm from 17.74 Nm. Finally, the old and the new drum design were analyzed using Solid-Works Cosmos software and it was observed that the drum displacement reduced from 15.22 inch to 9.572 inch and the design was found to be safe. For simplicity, the optimized values are listed in the table below.

Table 2: Optimized Parameters affecting the machine performance

Parameters	Speed	Torque	Power	Reduction in Drum Displacemnt	Reduction in water consumption
Value	1200 rpm	15.92 Nm	2.0 KW	43 %	75 %

Thus in totality a washing machine for daily use was optimized at a fairly reasonable cost.

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