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Vibration Analysis of a Horizontal Washing Machine, Part II: Isolation Efficiency

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Abstract:
The objective of this paper is to investigate the transmissibility and isolation efficiency encountered with the suspension of a horizontal washing machine. This analysis aims at reducing vibration and noise excited by the rotating unbalance during the spinning cycle of the washing machine. Through parametric analysis of the drum vibration of the washing machine, the detailed effect of the drum mass, suspension stiffness and suspension damping coefficient, it is possible to examine the variation of the transmissibility and isolation efficiency with the spinning speed of the machine. The isolation efficiency is presented for spinning speed from 600 to 1200 rev/min. It is possible through proper selection of the washing machine parameters to increase the isolation efficiency to about 96 %.

Keywords –*Horizontal washing machines, Vibration dynamics during spinning, Parametric analysis, Isolators efficiency.*

I. INTRODUCTION

Horizontal washing machines are an important domestic type of machines used for the welfare of the human being over years. Because of nature of the operation of the machine, its laundry acts as a rotating unbalance during the spinning cycle of its operation. This transmits very large forces to the cabinet and radiates noise. Therefore, the suspension parameters of the drum have to be properly designed to limit the vibration transmissibility and increase the isolation efficiency.

Papadopoulos and Papudimitriou (2001) presented a simplified 3-dimensional dynamic model for a horizontal washing machine. Their control based method eliminated instability and vibration and associated with active balancing [1]. Yanging. Zhiyan and Yiqi (2003) studied using an electromechanical coupling model for washing machine's drive and vibration attenuation system. They presented using a method adapting the rotary reference coordinate to avoid the complexity of [2]. Cooper and rice (2004) compared the cascade control and feedforward with traditional dynamic analysis method. They compared the application of nonlinear feedback decoupling control strategy with conventional control strategy where the former achieved more satisfying effect [2]. Hansen et. al. (2007) considered the design of the active and semi-active noise control system as a multi-variable optimization process. They discussed the optimal hierarchy for control followed by discussion of the optimization of various aspects of control system design. They have considered feedforward and feedback active control systems as well as semi-active systems and some ways of improving control system performance [3].

Kowalyshyn and Kwolkoski (2008) studied in details a case study in which significant measurement of vibration of a washer/extractor to isolate them from transmitting vibration to an elevated concrete floor slab [4]. Tyan, Chao and Tu (2009) developed a multibody dynamic model for a front loading washing machine with two MR fluid dampers. The suspension system composed of two springs and two MR dampers between the basket and case. They concluded that a PI controller reduced the vibration level of the basket and case at the same time [5]. Nygards and Berbyuk (2010) examined the capacity maximization, vibration output to surroundings and the walking tendency of washing machines. They built a computational model for the washing machine with bottom mounted suspension in Adams/View. They used the optimization results in the development of a new washing machine [6].

Boyraz and Gunduz (2013) derived a dynamic model of a horizontal washing machine to examine the vibration characteristics of the spin-cycle and improve its design using an optimization scheme based on genetic algorithms. They used a measurement method yielding the vibration displacement and vibration frequency from the acceleration data suitable for low cost diagnosis and active vibration control of the washing machine [7]. Mukhaje and Bhardwaj (2014) studied vibration control methods for front loaded washing machines. They stated the well known fact that washing machine vibration can be controlled using vibration isolation and damping pads [8].

Ma, Hu and Liu (2015) build a rigid-flexible coupling model using Adams/View and Adams/Vibration platform. They studied the effect of the suspension stiffness and damping coefficient on the vibration dynamics of the washing machine [9]. Hassaan (2015) investigated the effect of various parameters of the horizontal washing machine on the vibration displacement and velocity of the machine drum in terms of the spinning speed. He considered the effect of isolator stiffness, damping coefficient and the drum mass for a specific laundry capacity and eccentricity [10].

II. VIBRATING SYSTEM

The physical model of a horizontal washing machine during the spinning cycle is shown in Fig.1 [10], [11].

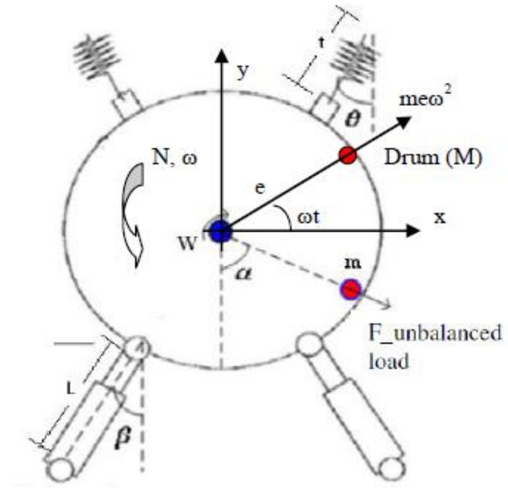


Fig.1 Horizontal washing machine physical model [10], [11].

A horizontal drum of mass M is isolated from the cabinet with two springs each has a stiffness k and two dampers each has a damping coefficient c. The inclination of the suspension (isolator) elements is Θ for the springs and β for the dampers. The wet laundry mass is m at an eccentricity e. The spinning speed is N rev/min.

III. MATHEMATICAL MODEL

The dynamic model of the drum vibrating system excited by the rotating unbalance of the laundry is derived by assuming that this vibrating system is a single degree of freedom one [12]. The dynamic motion is x and it has a natural frequency, damping ratio, exciting force and a steady-state vibration amplitude given by [10]:

$$\omega_n = \sqrt{(2k / M)} \quad \text{rad/s}$$
$$\zeta = 2c / (2M\, \omega_n)$$
$$F_i = me\omega^2$$

and

$$X = (me/M)r^2 / \sqrt{\{(1 - r^2)^2 + (2\zeta r)^2\}} \qquad (1)$$

Due to the vibration of the drum excited by the rotating unbalance, a dynamic force is transmitted to the cabinet through the inclined suspension elements. The transmitted force component in the x-direction, F_{tx} is the resultant of the elastic and damping force transmitted to the cabinet through the isolators. It is given by:

$$F_{tx} = 2kx(\sin\Theta)^2 + 2cx'(\sin\beta)^2 \qquad (2)$$

With $x = X\sin(\omega t - \varphi)$, the amplitude of the transmitted force is:

$$|F_{tx}| = 2kX(\sin\Theta)^2 \sqrt{[1 + (2\zeta r)^2]} \qquad (3)$$

where: $r = \omega/\omega_n$

$\omega = 2\pi N/60$ rad/s

The transmissibility TR of the vibrating drum is:

$$TR = |F_{tx}| / (me\omega^2) \qquad (4)$$

Combining Eqs.1,3 and 4 gives TR as:

$$TR = \sqrt{[1+(2\zeta r)^2]}/\sqrt{\{(1-r^2)^2 + (2\zeta r)^2\}} \qquad (5)$$

The isolation efficiency η is related to the vibration transmissibility as [13]:

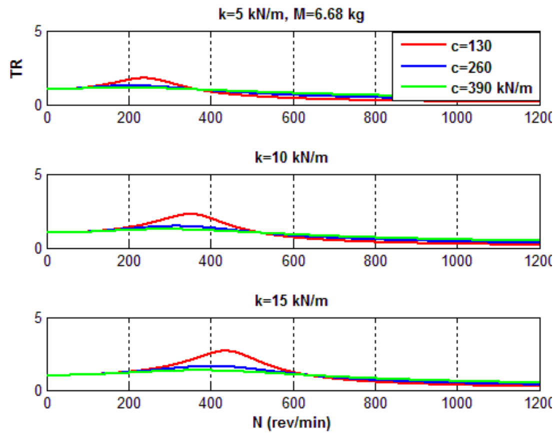
$$\eta = 100(1 - TR) \qquad (6)$$

IV. PARAMETRIC EFFECT ON TRANSMISSIBILITY AND ISOLATION EFFICIENCY

The drum mass and suspension parameters are used to investigate their effect on the transmissibility and isolation efficiency of the suspension for a laundry mass of 0.3 kg at an eccentricity of 100 mm.

1. Effect of M, k and c on the washing machine transmissibility:

- Effect of M = 6.68 kg and k = 5, 10 and 15 kN/m: Fig.2.



Fiig.2 Transmissibility for M=6.68 kg.

- Effect of M = 20 kg and k = and k = 5, 10 and 15 kN/m: Fig.3.

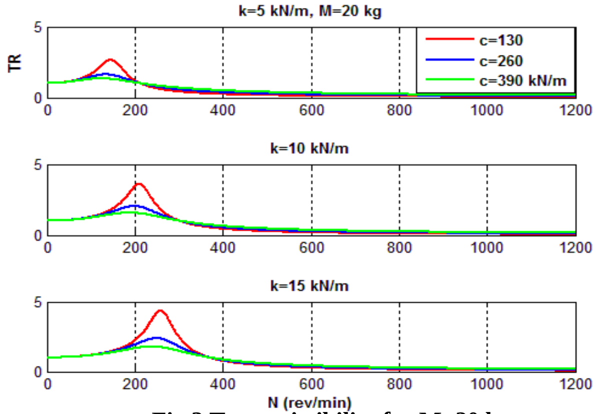


Fig.3 Transmissibility for M=20 kg.

- Effect of M = 30 kg and k = and k = 5, 10 and 15 kN/m: Fig.4.

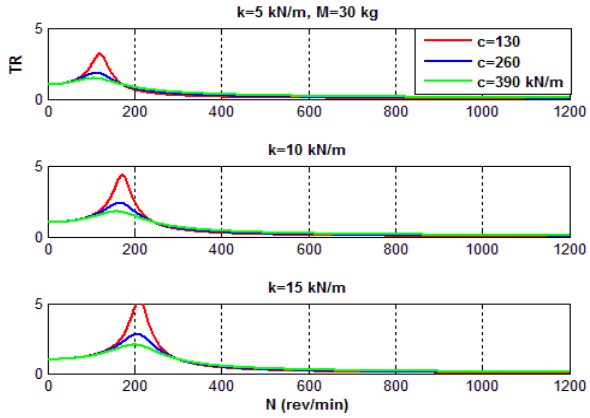


Fig.4 Transmissibility for M=30 kg.

2. Effect of M, k and c on the isolation efficiency:

- Effect of M = 6.68 kg and k = 5, 10 and 15 kN/m: Fig.5.

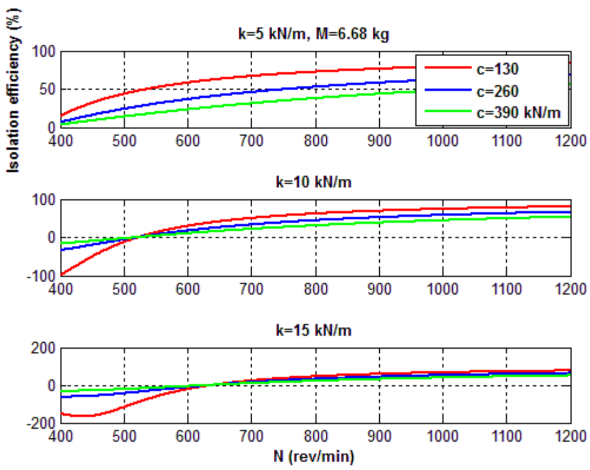


Fig.5 Isolation efficiency for M=6.68 kg.

- Effect of M = 20 kg and k = and k = 5, 10 and 15 kN/m: Fig.6.

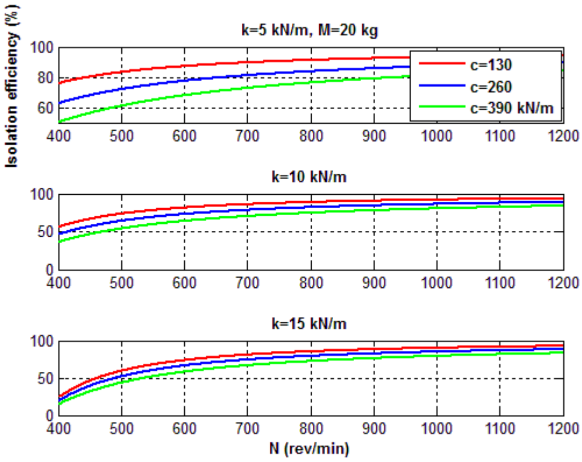


Fig.6 Isolation efficiency for M=20 kg.

- Effect of M = 30 kg and k = and k = 5, 10 and 15 kN/m: Fig.7.

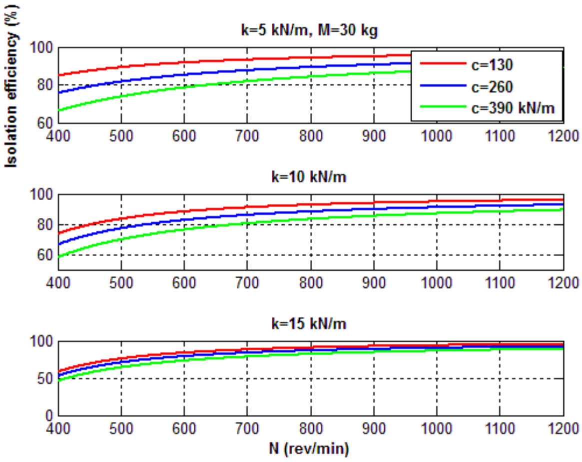


Fig.7 Isolation efficiency for M=30 kg.

V. BEST PARAMETRIC COMBINATIONB

Going through Figs.5 through 7 we come easily to a solid conclusion that the best combination of the isolators and drum mass parameters for maximum isolation efficiency is:

M = 30 kg , k = 5 kN/s and c = 130 Ns/m for a spinning speed ≥ 600 rev/min.

The effect of the spinning speed from 600 to 1200 rev/min on the suspension isolation efficiency is shown in Table 1.

Table 1: Isolation efficiency for M=30 kg, k=5 kN/m and c=130 Ns/m.

Spinning speed (rev/min)	Isolation efficiency (%)
600	91.58

700	93.12
800	94.18
900	94.92
1000	95.53
1100	95.98
1200	96.36

VI. CONCLUSION

- The vibration of a horizontal washing machine was analyzed for the transmissibility and isolation efficiency.
- The effect of drum mass, suspension stiffness and suspension damping coefficient on the transmissibility and isolation efficiency was investigated.
- The frequency spectrum of the transmissibility and isolation efficiency was plotted using MATLAB against the spinning speed of the machine.
- A spinning speed range up to 1200 rev/min was covered.
- The objective was to increase the isolation efficiency through selecting proper values for the drum mass and suspension parameters using parametric analysis.
- The study showed that it was possible to increase the isolation efficiency to about 96 %, which means that only 4 % of the exciting force is transmitted to the machine cabinet.
- This is a good achievement, but the problem here is that this achieved at high spinning speed where the vibration velocity of the drum is high as investigated in part I of this series of research work.
- To overcome this problem and compromise between isolation efficiency and vibration velocity, optimization techniques will be used in part III of this research.

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