e-ISSN: 2250-0758 | p-ISSN: 2394-6962
Volume-10, Issue-3 (June 2020)
https://doi.org/10.31033/ijemr.10.3.3

Performance Analysis of Multi-Body Modeled Washing Machines (MBomWM)

Asiya E. Asiya[1], Yomobong Amos I.[2] and Effiong A. Archibong[3]
[1]Department of Computer Engineering, Faculty of Engineering& Technology, University of Calabar, Calabar, NIGERIA
[2]Department of Physics, Electronics & Computer Technology, University of Calabar, Calabar, NIGERIA
[3]Department of Electrical & Electronic Engineering, Faculty of Engineering, Cross River University of Technology, Calabar, NIGERIA

[1]Corresponding Author: evangephraim@yahoo.co.uk

ABSTRACT

One of the key features of an automated washing machine is the noise and vibration it produces, or more technically, the decibel level it produces. Numerous of home appliance companies have put in much effort to solve this problem but there is still large room for further improvements especially in the rinse and the spin cycles of a washing machine. This work illustrates the performances of multi-body modelled of washing machines realized with the aim to analyze the vibrational acoustic emission. An experimental measurement has been carried out using a digital sound level meter (SLM) to determine the overall noise produced by four different modelled of automated washing machines with a view of noting the model with the highest sound pressure level during the three different cycles (the wash, rinse and spin). Results show that all the machines produced their highest noise during the spinning cycle. Out of the four different models considered, IPSO HF: 304 has the highest sound level of 99.62dB during its spin cycle when a maximum load of 30Kg was applied, followed by Imesa RC 23 with a 96.13dB. On the other hands, LG: Direct Drive 13 has the least sound pressure level of 84.75 dB. With this knowledge in mind, one can advise a buyer of which model to purchase from the market and if an operator must use the machine, how long he can operate such machine without health challenges.

Keywords-- Automated Washing Machine, SPL, SLM, Noise, Vibration

I. INTRODUCTION

A washing machine has more possible noise sources in comparison to other large household electronic appliances [1, 2]. This is due to the existence of complex dynamic assemblies and subsystems narrowed to suit inside a tight design space. Due to wide-ranging of governmental standards globally, increased washing machine design complexity, and the necessity for rapid product development cycle and time to market, it is important to develop a more efficient methodology to address noise and vibration issues [3]. This is because, noise and vibration causes serious problems, both at home and at workplace, and the task of reducing community noise is a subject currently focused on by experts in various countries. Similarly, manufacturers of mechanical products with vibrations causing acoustic noise, more and more find themselves forced to compete on the noise levels of their products [4, 5].

In this research, performance analysis was carry out to test the vibration and noise level of different washing machines during three different cycles (the wash, rinse and spin) with a view to determine which model has the highest sound pressure level.

II. BACKGROUND OF STUDY

Noise levels in domestic appliances is captivating attention from producers because of increased regulation and understanding from customers [2].
Sergio [6] made an attempt to employ a combination of finite-element and multi-body dynamics (MBD) for determining the resonant vibration modes and transient structural response to capture dynamic performance during the initial design phase of the entire machine.This was then combined with indirect boundary-element models for the performance of sound field analysis to detect the effects of sound-absorbing cotton fleece mats of different thicknesses surrounding the washing machine [7].

Hybrid approach – combining numerical techniques and experimental methods have also been developed by Siavoshani and Barpand [8, 9] to address floor-pan vibration and the outcome of the radiated noise in automotive vehicle. This methodology has been effectively adapted for reducing the entire noise level in a standard top-loading washing machine.

Barpanda, [8] presented an article for a six-sigma approach for isolating root cause as well as in addressing high noise emanations from a front-load washer-cum-dryer (W/D) machine during common operating conditions. This article was aim to: (1) characterize the “noise” radiation (source/level) of the combination unit in all the three operative modes using IEC60704 standards. (2) identify the root cause of the maximum radiated noise level. (3) test potential material/design possibilities for addressing noise reduction initiatives and (4) develop product-neutral solution portfolio options (performance/mass/cost).

III. TYPES OF WASHING MACHINES

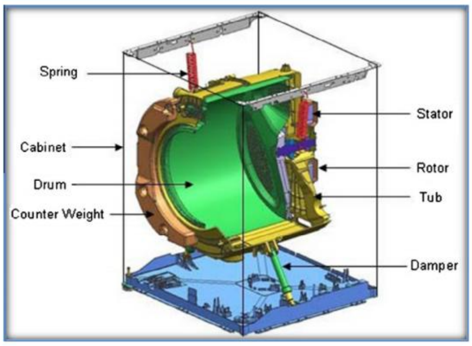
a) Drum-type washing machine: This comprises of cabinet, tub, spring, counterweight, drum, rotor, stator, and damper. In the cabinet, the tub is mounted to store the water for laundry; the rotor is the power source for rotating the drum, is connected with the drum directly; the stator is immovable on the back of the tub. Once the drum starts rotating, the mass imbalance due to eccentricity of laundry generates the vibration, this vibration produced by the drum and tub is then transmitted to the cabinet and the bottom through the damper and spring. At this point, if the inertial moment of the energetic system is amplified to restrain the vibration, the washing machine becomes heavy and the reactive force on the bearing gets also amplified [10]. Consequently, the drum and the tub need to be designed to have higher rigidity and strength.

The drum-type washing machine is further subdivided into;

- front-loader
- a traditional top-loader
- a high efficiency top-loader

Each of the above has its pros and cons. The choice of purchase is therefore dependent on the choice of the buyer.

A three-dimensional (3D) schematic diagram of the washer is shown in fig. 1(a), this washing machine is object of soul's work, it is a prototype based on the LG F14 02FDS washer manufactured by LG Electronics [8].



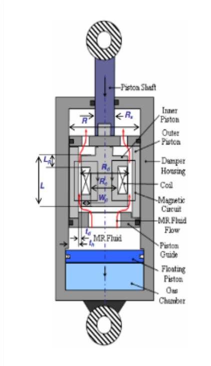


Fig. 1: (a) 3D Schematic of the Prototype Washing machine (b) Schematic configuration of the MR damper.

Fig. 1(b) displays the schematic configuration of a flow-mode magneto-rheological (MR) damper proposed for the prototype washing machine. From this figure, it can be seen that an MR valve structure is integrated in the MR damper. The external and internal pistons are integrated to form the MR valve structure which splits the MR damper into two compartments: the upper and lower compartments. These compartments are completely filled with the MR fluid. As the piston rotates, the MR fluid runs from one compartment to the other through the annular orifice. The floating piston incorporated with a gas chamber functions as an accumulator to house the piston shaft volume as it goes in and leaves the fluid chamber [11, 12].

IV. MATERIALS AND METHOD

A) Materials

Four different models of automated washing machines were considered in this work, among these were those tabulated in table 1 below. The table also depicts the specifications of the above mentioned machines.

The reasons for choosing these machines were;

i) they were the only ones readily available.

ii) to experimentally determine which of the model has less or high level of noise during the three phase of operational processes.

Table 1: Machine specification

S/N	Brand	Model type	Maximum load capacity (Kg)	Specialty
1	Imesa RC 23	Front loader	30	Wash, Spin
2	IPSO: HF304	Front loader	30	Wash, Spin
3	IPSO: HF185	Front loader	18	Wash, Spin
4	LG: Direct Drive 13	Front loader	8	Wash, Spin

Other materials were; Load (mass of clothes), Water, Liquid detergent and Digital Sound level meter (DSLM)

e-ISSN: 2250-0758 | p-ISSN: 2394-6962
Volume-10, Issue-3 (June 2020)

https://doi.org/10.31033/ijemr.10.3.3

B) Methodology

An MS6700 DSLM with a range of 30-130dB conformed to IEC651 was used to collect SPL measurements of different washing machines inside the operational room during the three phase.

Electrical power and water to the machine were piped to the room and control measures were taken to ensure that noise(s) from the water flow were not influencing the tests. Furthermore, measurements were collated to ensure that the source noise was at least 15 dB higher than the background noise. Since the main objective of the test was to compute the overall sound power level of different models of automated washing machines, the microphones of the SLM was placed in different spinning positions of the machine, as depicted in figure 3 (a-c). The meter measured the SPL of the washing machine noise emission in the free field.

The measurements were taken for five consecutive times by time averaging for 30 seconds and then A-weighted. The overall sound power level was computed for all cases and recorded. The meter readings were also calibrated with an audio Real Time Analysis software in order to abate the meter's error.

(a) (b) (c)

Fig.3: Measurement of overall noise power level with SLM at different (a) washing (b) rinsing and (c) spinning positions of the machines.

Calibration

The SLM readings were calibrated with Real Time Analysis audio software in order to correct the meter's error. The calibrations were done at an audio frequency range of 20-20kHz over SPL range of 0dB-150dB at 1 octave and presented in figure 4 (a-d).

Computation

To compute the sound power level, the SPL was averaged over the surface area and integrated over the frequency bands. The sound intensity level of the radiated noise from the washing machine is given by;

$$L_I = L_P - 10\log K \quad \ldots \quad (1)$$

Where, K is a constant dependent on the ambient pressure and temperature.

From theory, at 25°C and typical atmospheric pressures, the constant K is approximately a unity (i.e 1); thus, the second term of the RHS of equation (1) was ignored and the sound intensity approximated to:

$$L_1 = L_P \quad \ldots \quad (2)$$

Similarly, the SPL is given by:

$$L_W = \sum_j^n S_i \ X \ 10^{L_{pi}/10} \quad \ldots \quad (3)$$

Where, $S_i$is the area of each segment (i) of the enclosure.

The sound power for each one octave band was then integrated over the entire range of frequency to give the overall level. These measurements and computations were accomplished for the modelled machines and after every product changes.

V. RESULTS

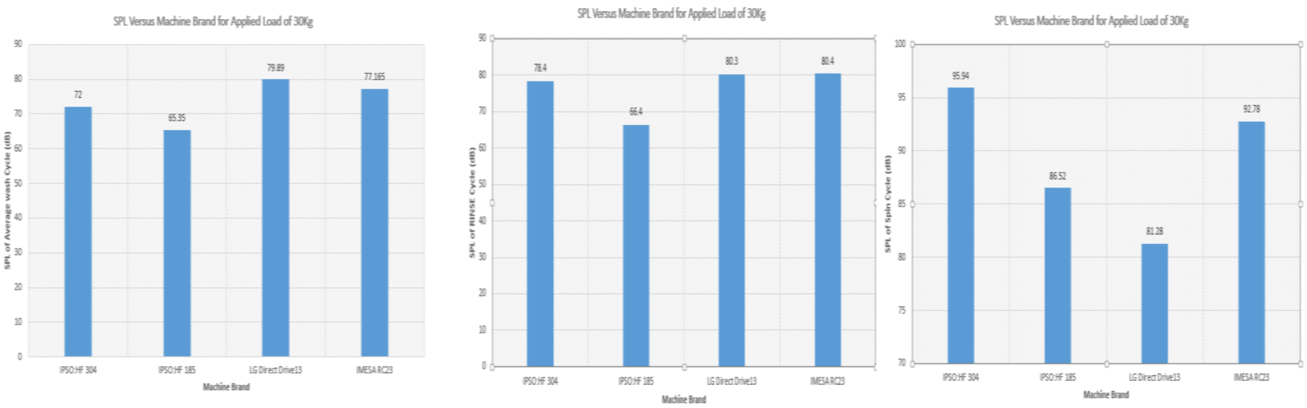
Four different brands of machines ran through the three different cycles, the wash, the rinse and the spin cycle to determine the exact operational mode that radiated the maximum noise (quantify and qualify). The overall sound power level was computed for each case as shown in table 2.

e-ISSN: 2250-0758 | p-ISSN: 2394-6962
Volume-10, Issue-3 (June 2020)
https://doi.org/10.31033/ijemr.10.3.3

Table 2: Specific operational mode showing progressive noise radiation with applied loads for the four brand of machines.

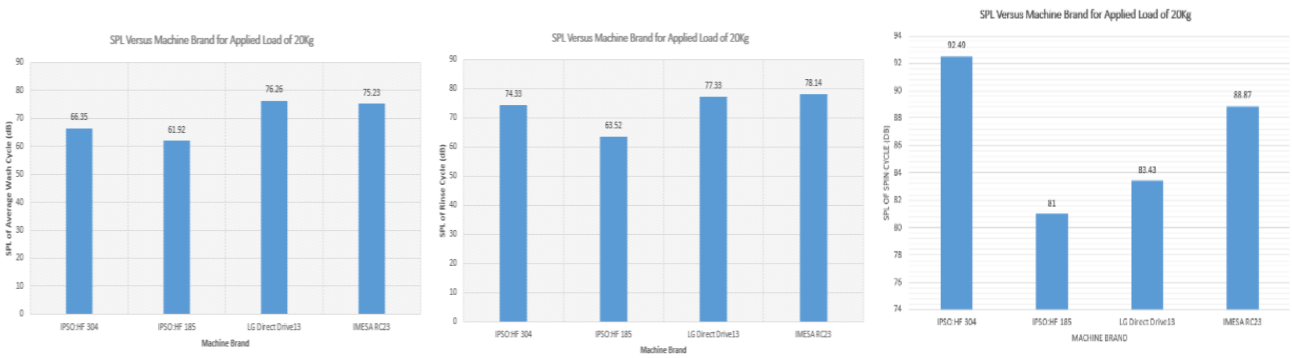
Machine Brand	Machine's Max. Capacity (Kg)	Applied Load (Kg)	1st Wash Cycle (dB)	2nd Wash Cycle (dB)	Average Wash Cycle (dB)	Rinse Cycle (dB)	Spin Cycle (dB)	
IPSO:HF 304	30	30	70.7	73.3	72	78.4	95.94	1st Experime-ntation
IPSO:HF 185	18	30	66.2	64.5	65.35	66.4	86.52	
LG Direct Drive13	8	30	79	80.78	79.89	80.3	81.28	
IMESA RC23	30	30	77.23	77.1	77.165	80.4	92.78	
IPSO:HF 304	30	18	67.5	65.2	66.35	74.33	92.49	2nd Experime-ntation
IPSO:HF 185	18	18	62.34	61.5	61.92	63.52	81	
LG Direct Drive13	8	18	74.69	77.83	76.26	77.33	83.43	
IMESA RC23	30	18	75.46	75	75.23	78.14	88.87	
IPSO:HF 304	30	10	65.7	68.22	66.96	73.46	83.87	3rd Experime-ntation
IPSO:HF 185	18	10	61.44	58.85	60.145	60.55	64.3	
LG Direct Drive13	8	10	76.59	76.77	76.68	74.54	79	
IMESA RC23	30	10	73.69	73.1	73.395	77.48	84.6	

The average SPL was then computed for the SLM for the wash cycle and it was observed that, the spin cycle radiated the highest noise and this was greater than all other modes of operations for the entire machine brands with respected to the applied load.



(a) (b) (c)

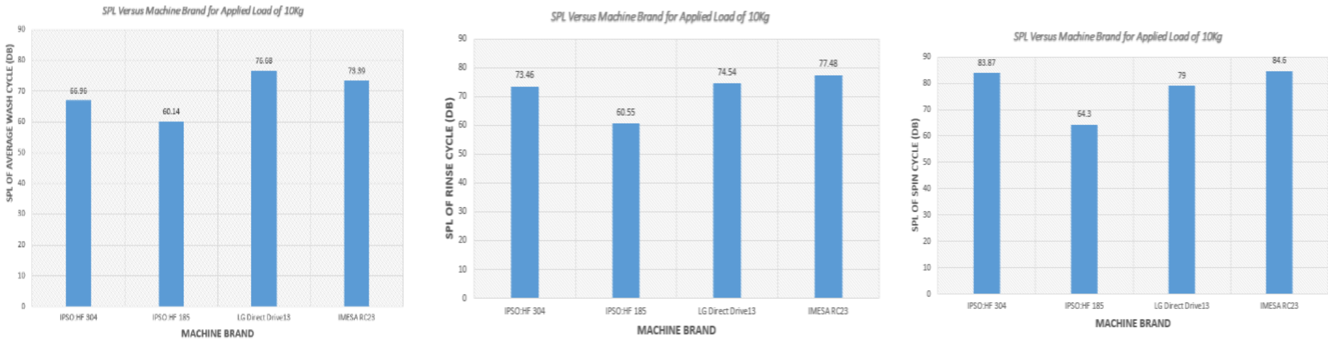
Fig. 4 (a-c): Plot of SPL against machine brand for the three cyclic mode with an applied load of 30 kg



(a) (b) (c)

Fig. 5 (a-c): Plot of SPL against machine brand for the three cyclic mode with an applied load of 20kg

e-ISSN: 2250-0758 | p-ISSN: 2394-6962
Volume-10, Issue-3 (June 2020)
https://doi.org/10.31033/ijemr.10.3.3



(a) (b) (c)

Fig. 6 (a-c): Plot of SPL against machine brand for the three cyclic mode with an applied load of 10 kg

It is shown from figure 7 (a-d) that the noise radiated contains a wide range of frequencies and the noise profile does not significantly change with increase in the rotation speed of drum.

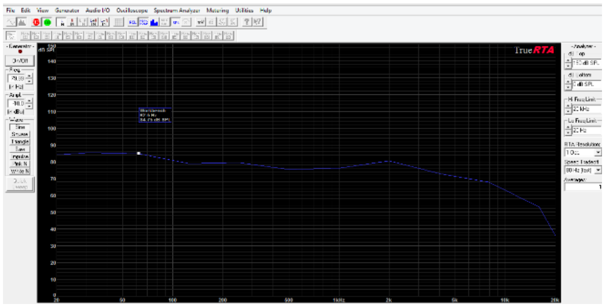


Fig. 7c: Calibration of SLM measurement for the spin cycle of LG Direct Drive 13 at SPL of 81.28dB with applied load of 30 kg

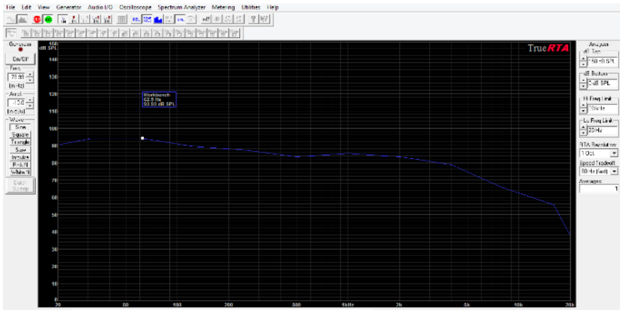
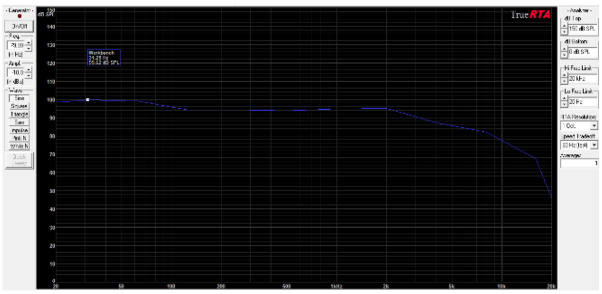


Fig. 7d: Calibration of SLM measurement for the spin cycle of Imesa RC23 at SPL of 92.78dB.



7a: Calibration of SLM measurement for the spin cycle of IPSO:HF 304 at SPL of 95.94dB with applied load of 30 kg

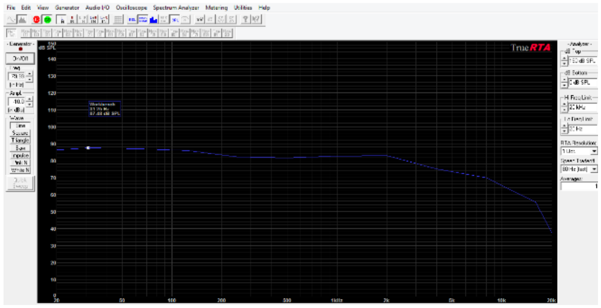


Fig. 7b: Calibration of SLM measurement for the spin cycle of IPSO:HF 185 at SPL of 83.52dB with applied load of 30 kg

Analysis

An analysis has been carried out, this help in understanding of the root-causes driving the defects. The noise sources were identified using the SPL meter measurements.

To understand the reason (source) behind high noise emissions at the maximum RPM level in the spin cycle, measurement were taken around;

- the steel wall panels
- near the pump
- near drum motor
- drum drive belt

Similarly, to understand the influence of pump noise, SPL measurements were taken with the microphone of the SLM closer to the drain pump. Two different sets of measurements were taken, with only the pump switched on (no spin cycle) and vice versa.

The vibrations of the drum motor and casing were also measured to determine if these were significant sources contributing to overall radiate machine noise and vibration. These measurements show high motor vibrations followed closely by the drum casing.

e-ISSN: 2250-0758 | p-ISSN: 2394-6962
Volume-10, Issue-3 (June 2020)
https://doi.org/10.31033/ijemr.10.3.3

Table 3: Vibration of the drum motor and casing during the operational process of spinning of the machines.

S/N	Machine Model	Applied Load (kg)	Vibration of Casing during Spin Cycle (dB)	Vibration of drum motor during Spin Cycle (dB)
1	IPSO (HF 304)	20	56.78	68.4
2	IPSO (HF 185)	20	60.70	62.4
3	LG Direct Drive13	20	57.3	69.02
4	IMESA RC23	20	60.64	71.24

VI. CONCLUSION

In conclusion, an automated washing machine has more potential noise sources compared to other large household electronics appliances. This is due to the presence of complex dynamic assemblies and subsystems cramped to fit within a tight design space.

In an attempt to mitigate the problems associated with noise and vibrations, it was pertinent to study the actual effects of automated washing machines on either humans, structures or environment as observed.

This work was aimed at performance analysis of various automatic washing machines using experimental method to predict the brand with the least and highest SPL as well as to provide information that can help to regulate design specifications in view of preventing health challenges due to noise, vibrations and life span of such machines.

From our results, a digital sound level meter reveals that different models of automated washing machines under consideration has their highest SPL at the spin cycle as compared to rinse and wash cycles.

Imesa RC 23, IPSO: HF185, IPSO: HF304 and LG: Direct Drive 13 were the four different types of washing machines that were readily available during this research work, after the SPL's calibration as seen from our findings [in fig. 4, 5, 6 (a-c)], IPSO: HF304 produced the highest noise level of 99.62dB during the spinning cycle, followed by Imesa RC 23 with 96.13dB. On the other hand, IPSO: HF 185, has 87.48dB against LG: Direct Drive 13 with 84.75dB as the least noisy washing machine respectively.

REFERENCES

[1] International Electrotechnical Commission. (2004). *Household and similar electrical appliances test code for the determination of airborne acoustical noise*. IEC 60704-2-10 Ed.

[2] IEC. (2004). *Household and similar electrical appliances test code for the determination of airborne acoustical noise.* IEC 60704-2-10 Ed.

[3] Commission, E. (2010). Commission Regulation (EU) No 1015/2010 of 10 November 2010 implementing directive 2009/125/EC of the Euro pean Parliament and of the Council with regard to Eco-design requirements for household washing machines.In:*Official Journal of the European Union.* Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32010R1015.

[4] Conrad, D.& Soedel, W. (1995). On the problem of osci llatory walk of automatic washing machines. *Journal of Sound Vib., 188,* 301-314.

[5] Kelly, G. (1996). *Schaum's outline of theory and problems of mechanical vibrations*. New York, USA: McGraw-Hill. pp. 64-85.

[6] Sergio, A. D. (2003). The design of washing machine prototype. *Materials and Design, 24,* 331-338.

[7] Lee, J. Y. (1998). Modeling and dynamic analysis of a front loaded washing machine. *Journal of Soundand Vibration of Korea, 8*(4), 670-682.

[8] Murray P., Henderson, M.I., Marcetic, D., Marcinkiewicz, J.G., Sadasivam, V., & Rajarathnam, A.V. (2004.). *Method and system for determining washing machine load unbalance*. US Patent 0,211,009 A1.

[9] Barpanda, D., Tudor, J. M., & Siavoshani, S. J.(2007). *An engineering approach to noise abatement in washing machines.* Paper Number 334, NOISE-CON, Oct 22-24, Reno, NV.

[10] Jong-Soo Choi, Dennis K. McLaughlin, &Donald E. Thompson. (2003). Experiments on the unsteady flow field and noise generation in a centrifugal pump impeller. *Journal of Sound and Vib., 263,* 493-514.

[11] Ryan, K.F.& Sribar, R. (2000). Horizontal axis clothes washing machine with balance rings. *US Patent 6*, 158,257.

[12] Donida, F., Ferretti, G., & Schiavo, F. (2006). Modeling and simulation of a washing machine. In: *Proceedings of the 50th International Anipla Congress.* Roma, pp. 14–15 .

[13] Green, K., Champneys, A.R., Friswell, M. I.,& Muñoz, A.M. (2008). *Investigation of a multi-ball, automatic dynamic balancing mechanism for eccentric rotors.* Phil. Trans. R. Soc. A. DOI: 10.1098/rsta.2007.2123.