Development of Internet of Things Model for Acoustic Maintenance of Boilers

S.N. Dhludhlu
Department of Mechanical and Industrial Engineering Technology
University of Johannesburg, South Africa.
217017226@student.uj.ac.za

D. V. V. Kallon
Department of Mechanical and Industrial Engineering Technology
University of Johannesburg, South Africa.
dkallon@uj.ac.za

Abstract

This report documents the design of an acoustic horn and development of internet of things (IoT) model for acoustic maintenance of boilers. The aim was to design an acoustic horn cleaner which use acoustic energy or sound waves to blast off particles build-up from the boiler tubes while the boiler is operating. AutoCAD Invertor 2021 was used to generate a modelled acoustic horn which was then simulated using real life forces, pressures and temperatures encountered in the operation of the boilers. Different sources were also used to develop an Internet of Things model. The application of the acoustic cleaner is in a boiler which is a critical environment with an approximate pressure of 552 kPa and a maximum temperature of 300 °C. Stress (static ad transient dynamic) and thermal analysis simulations were conducted on the critical components of the design using Ansys R2 student version. The deflection of the diaphragm was determined under the action of maximum pressure supplied by the compressed air to deflect to approximately 0.546 m without restrictions.~~,~~ However, in actual sense the Diaphragm deformation is restricted by the Housing and thus, excessive deformation above 100mm of the diaphragm is unlikely. The endcap of the housing has a deflection allowance of 80mm which is enough for the membrane to vibrate at natural frequency of 75.322 Hz. An IoT model was developed for remote access to the developed acoustic cleaning system. The developed IoT boiler maintenance model is also known as a smart boiler model.

Keywords
Acoustic horn cleaner, Internet of Things, Boiler maintenance

1. Introduction

Nowadays one of the common ways to generate electricity is by burning of fossil fuels such as coal in order to heat steam in boilers at high temperatures to rotate steam turbines thereby producing electricity. This research focuses on the maintenance of boilers using an acoustic horn and the development of Internet of Things model for boiler maintenance (Shandu and Kallon, 2020a: Shandu et al, 2019). Boiler cleaning plays a very important role in increasing the efficiency of a boiler. Improving the efficiency of pulverized coal (PC) fired boilers has been the focus of considerable efforts by the utility industry since it leads to several benefits (reduced emissions and consumption of coal per MWe). Typically, a one percent improvement in overall efficiency can result in a nearly three percent reduction in CO_2 emission (Sankar, 2019).

The internet of things (IoT) is now considered a new generation of internet technology. IoT is a system of interrelated computing devices that can transfer data over a network without requiring human-to-human or human-to-computer interaction. This research focuses on adopting ways which to use the current internet technology in maintaining the boilers. One of the proposed solutions is to install IoT sensors (smart boiler concept) around the boilers which will send information about the situation of the boiler whenever maintenance is required without switching off the boilers. This is seen as one of the ideas that will minimize the cost of boiler maintenance. The smart boiler concept is an advanced plant operations and maintenance solution that allows plant operators and management to track the performance of their boilers using a variety of plant sensors and cloud-based analytics (SmartBoilerTM, 2018). The Internet of Things (IoT) can also be defined as a network of interconnected, internet-connected devices that can receive and transmit data without the need for human interaction over a wireless network. Wireless controls, applications, actuators, and computing systems are examples of IoT devices (Yoon, 2020). In our case this can mean the use of smart surveillance, sensors, environmental monitoring systems and automated acoustic horns for an automated boiler maintenance.

The main idea in PdM is to anticipate failures just before they occur avoiding unscheduled machine stops and production halt while maximizing equipment life usage (Rieger et al., 2019). To make these predictions, real time data must be stored and analysed taking into consideration different aspects and effects of the collected signals. In this context, AI, and, especially, Neural Networks with Deep Learning techniques and processing algorithms, have the capacity of turning Big Data into actual information that can be used to make decisions.

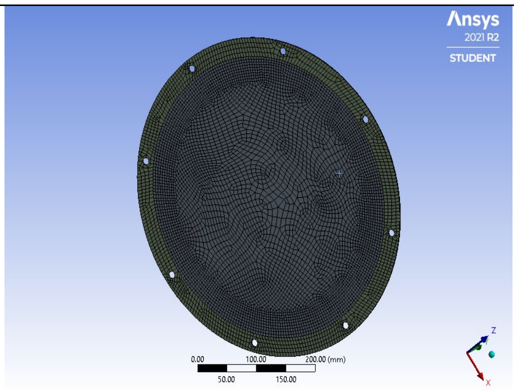
Despite the rapid growth of IoT in the maintenance business, there are several obstacles to overcome, such as managing heterogeneity, design, trust, privacy, and security are some of the challenges (Farooq & Muhammad W, 2015). To enable IoT, the heterogeneity of multiple devices, environments, and applications must be controlled. The issues in developing IoT include how to create efficient architecture, mechanisms, and protocols, as well as how to create efficient architecture, mechanisms, and protocols, as well as how to handle with large amounts of data in order to deliver effective services. How to secure the IoT architecture and protect the user's personal information are the trust, privacy, and security problems. Only 26% of IoT projects were successful, according to a Cisco assessment of 1800 stakeholders in IoT efforts conducted in 2017 (Dachyar, 2020).

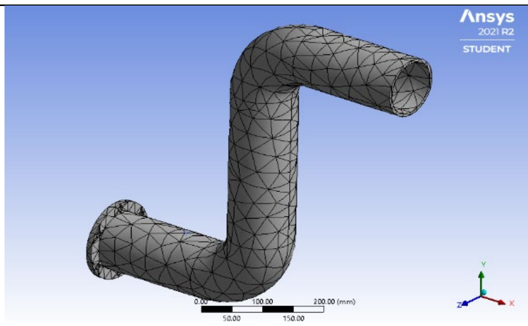
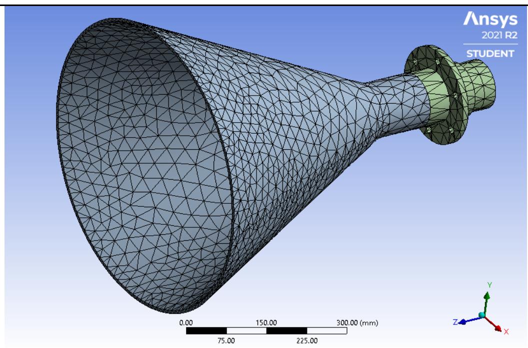
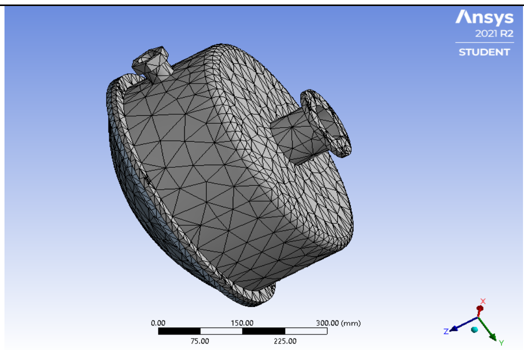
2. Materials and Methods

2.1 Meshing

Generating a mesh is an imperative step when doing computational mechanics. In order to analyze the performance of the components and how they behave, meshing properties were created to solve the governing equations in sub-domains made of nodes and elements which results in more accurate behavioral predictions. Table 1 shows the meshing properties for each component simulated.

Table 1. Meshing the model components

Component	Figure	Mesh Properties
Diaphragm		46733 nodes 6362 elements

Pipe		5092 nodes 2451 elements
Horn		14848 nodes 7014 elements
Housing		14259 nodes 6733 elements

2.2 Harmonic Response Analysis

A harmonic response analysis was performed to determine the response of the diaphragm to the oscillating or harmonic load due to the pressurized air. A harmonic analysis was performed with 5.52 bar pressure load on the membrane, with restricted movement or degrees of freedom, Figures 1-3.

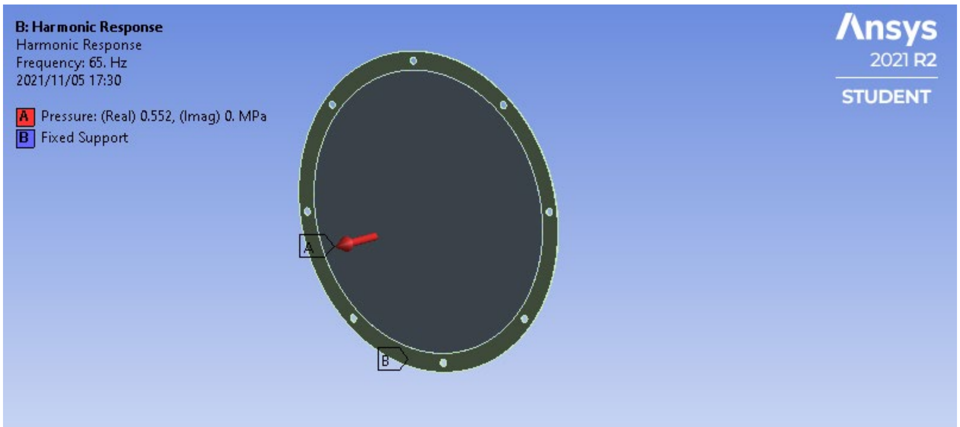


Figure 1. Diaphragm harmonic analysis constraints.

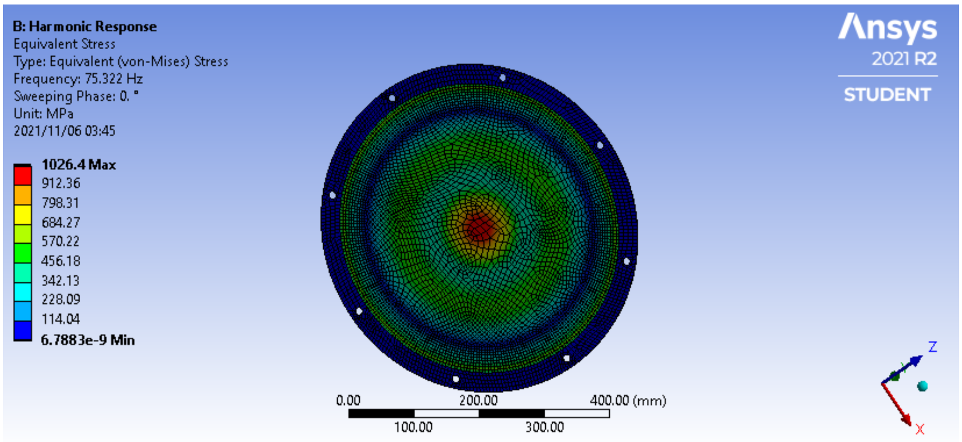


Figure 2. Diaphragm harmonic analysis equivalent stress.

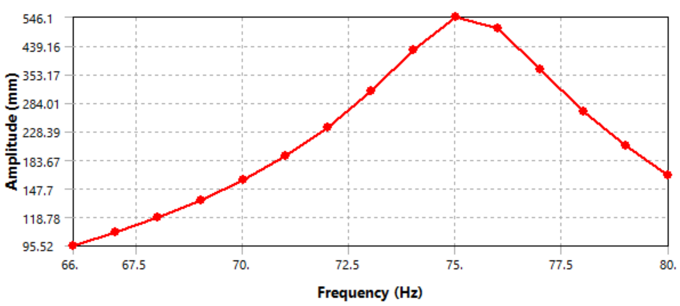


Figure 3. Deformation frequency response in z-axis.

2.3 Internet of things methods

Different technical communications models are used in the IoT implementation, each with its unique set of features. These are Device-to-Device; Device-to-Cloud; Device-to-Gateway; and Back-End Data-Sharing which are four popular communication modes, Figure 4.

2.3.1 Ensuring Security of the plant

A VPN-firewall for distant connections, similar to that employed by other IoT service centers, is included in the system. A LAN-to-LAN VPN tunnel protects the distant connection. The model also communicates any data to the plant DCS, therefore data gathering from the plant DCS is a two-way link. For all third-party connections, the plant DCS will first have a firewall.

3. Results

Any Logic software is used to create an agent-based simulation in this research study. This investigation is restricted to one boiler and one acoustic horn cleaner. The sequence diagram (shown in Figure 5) which illustrates the sequence of instructions and messages that occur between agents. It illustrates the process sequence from its occurrence to the transmission of a repair request, for boiler maintenance.

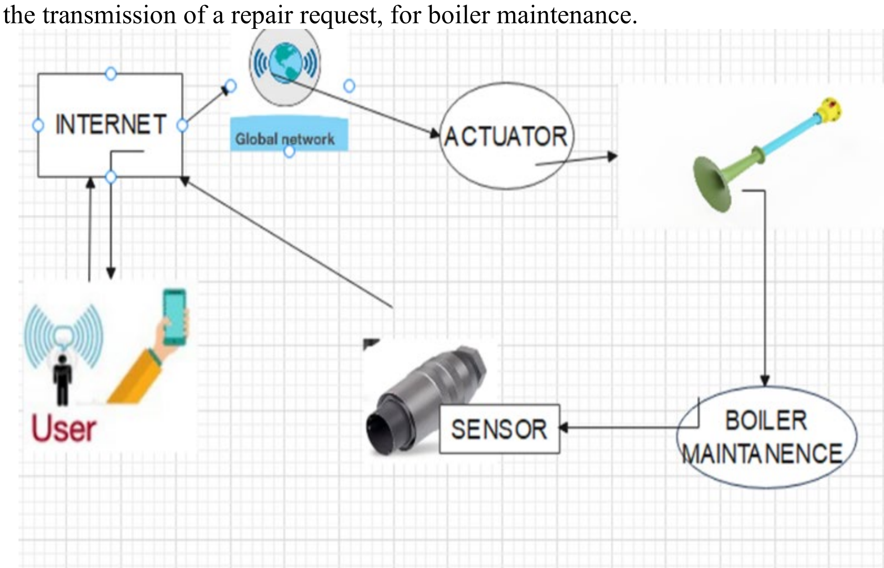


Figure 4. Internet of things model.

Figure 4 obtained from (SmartBoilerTM, 2018) which shows a series of monitor screens graphically presenting the plant's process data and analytical data for a plant operator in the plant control room. This graph shows which type of data will be obtained by the Internet of things model sensors from the boiler and plant for boiler maintenance. For instance, an acoustic monitoring system is used to monitor the flue gas path and boiler structures to give early warning of impending problems. The model can also use a boiler leakage detection module to closely monitor furnace walls and other boiler heat exchange surfaces and, based on regression models using real process data and self-learning algorithms to predict future problems so that maintenance may be planned in advance and restoration time minimised.

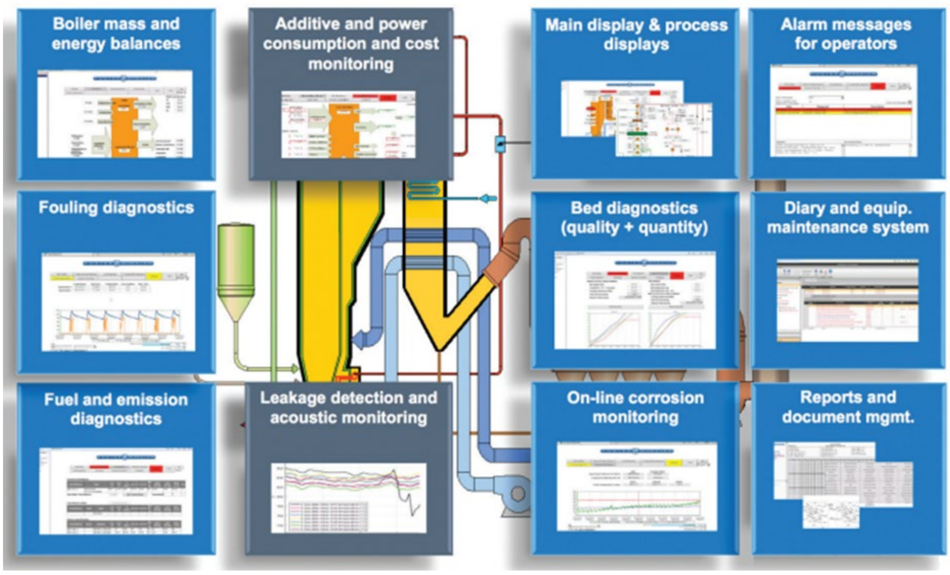


Figure 5. Smart boiler applications and tools

3.1 Acoustic horn

Table 2 shows the calculated critical stress results at points which were assumed-to be the critical points of failures for each component.

Table 2. Calculation results

Components	σ_Θ (MPa)	σ_r (MPa)	σ_z (MPa)
Diaphragm housing	6.21	0.279	0
Connecting pipe	10.304	0.279	0
Horn/cone	82.8	0.279	0
Mounting Bracket	16.56	0.279	0
Most critical value	82.8	0.279	0

Figure 6 shows the results of the natural frequencies of the Diaphragm at different modes of vibration. The first mode of vibration occurs at a natural frequency of 75.322 Hz which is close to the desired 75 Hz. This indicates that the diaphragm design does indeed vibrate at first mode at 75Hz of frequency with a deformation of 71.434 mm.

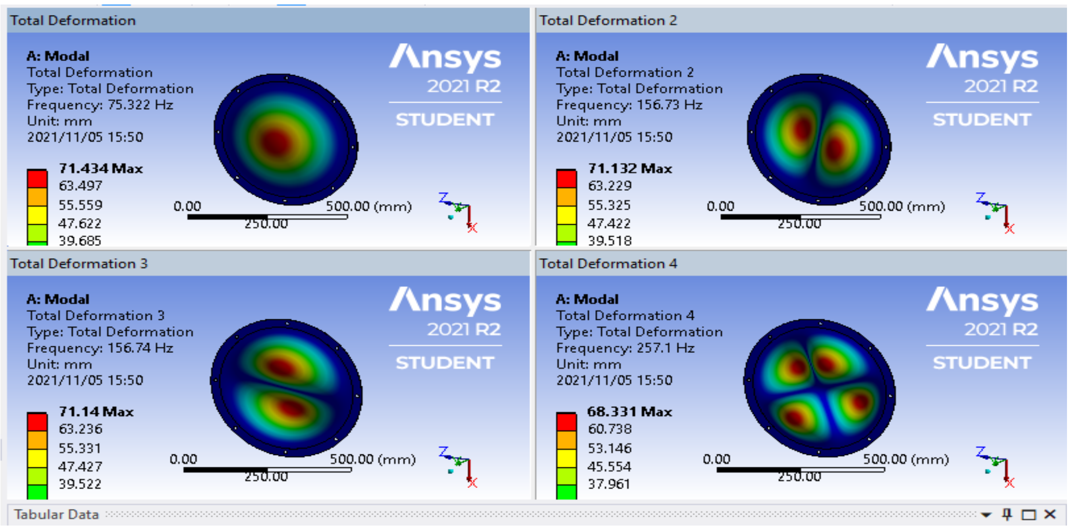


Figure 6. Diaphragm simulation

For the deformation response to the harmonic pressure load, it was observed that the deformation in the range of 65 to 80 Hz will reach a maximum value at resonance when the frequency matches 75.332Hz. The Diaphragm will deflect to approximately 0.546m without restrictions, however, in actual sense the Diaphragm deformation is restricted by the Housing and thus, excessive deformation above 100 mm of the diaphragm is unlikely. The endcap of the housing has a deflection allowance of 80mm which is enough for the membrane to vibrate at natural frequency of 75.322 Hz with deflection of +70 mm. The deformation due to the harmonic pressure load is close to the calculated deformation of the Diaphragm which was found to be 0.599m at 5.52 bar when the membrane is not restricted in the area on which the pressure acts.

A maximum stress of 1026.4 MPa is experienced at the centre of the Diaphragm, this value, does not exceed the yield strength of the material which is approximately 1100 MPa. The diaphragm can be expected to not undergo permanent deformation. Table 3 shows results comparing the critical stress from calculations with the results found on simulations. The most critcal stress is experienced by the diaphragm housing as the compressed air enters from there to resonate the vibrations.

Table 3. Calculated vs stimulated critical stresses

Components	Calculated	Simulated	
		Min (MPa)	Max (MPa)
Diaphragm housing	6.21	640.01	3.08×10^7
Connecting pipe	10.304	0.0025735	0.08463

Horn/cone	82.8	0.00021054	1.1282
Mounting plate	16.56	$8.210x10^{-5}$	540.78
Diaphragm plate		$2.558x10^{-16}$	864.9
Most critical value	82.8	640.01	$3.08x10^{7}$

5. Conclusions
The simulations indicate that the Acoustic horn assembly has an output of 75.322 Hz frequency. The Diaphragm that generates this frequency is not subjected to excessive stresses and hence does undergo permanent or excessive deformation which will lead to fracture (Shandu and Kallon, 2020b). The diaphragm housing assembly that houses the diaphragm restricts the amount of deflection of the diaphragm to 80mm and thus as the diaphragm will be able to expand and allow for the evacuation of the pressurized air particles without exceeding deformation of 80mm.

Acknowledgments
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Biographies
Mr. Sbusiso Dhludhlu is a recent Bachelor of Engineering Technology honors in Mechanical Engineering graduate from the University of Johannesburg. He is registered as a candidate technologist with the Engineering Counsil of South Africa. He is currently doing his internship as a pump technician in one of the pump manufacturing companies in South Africa and outside. He a self-driven, goal orientated individual who believes in lifting and empowering others, through the knowledge he has acquired, and experiences gained overtime.

Dr. Daramy Vandi Von Kallon is a Sierra Leonean holder of a PhD degree obtained from the University of Cape Town (UCT) in 2013. He holds a year-long experience as a Postdoctoral researcher at UCT. At the start of 2014 Dr Kallon was formally employed by the Centre for Minerals Research (CMR) at UCT as a Scientific Officer. In May 2014 he transferred to the University of Johannesburg as a full-time Lecturer and later a Senior Lecturer in the Department of Mechanical and Industrial Engineering Technology (DMIET). Dr Kallon has more than twelve (12) years of experience in research and six (6) years of teaching at University level, with industry-based collaborations. He is widely published, has supervised students from Master to Postdoctoral levels and has graduated seven (7) Masters Candidates. His primary research areas are Acoustics Technologies, Mathematical Analysis and Optimization, Vibration Analysis, Water Research and Engineering Education.