SIMULATION OF AN ACOUSTIC DEVICE FOR ONLINE CLEANING OF BOILERS AT SASOL SYNFUELS POWER STATION IN SECUNDA

Purity Mimi Shandu
Department of Mechanical and Industrial Engineering Technology
University of Johannesburg
Johannesburg, South Africa
mpshandu@gmail.com

Daramy Vandi von Kallon
Department of Mechanical and Industrial Engineering Technology
University of Johannesburg
Johannesburg, South Africa
dkallon@uj.ac.za

ABSTRACT

This paper assesses the acoustics technology as a possible solution to online cleaning of coal fired boilers. An acoustics device is designed in AutoCAD Invertor professional 2016, where simulations are performed and compared with calculations done to determining if the acoustic device can be used for boiler cleaning or as a backup system to soot blowers, popularly used in South Africa. The similarity law was used to determine the frequency of the beam that will be suitable for an acoustic horn with a frequency of 75Hz when varying forces ranging from 40N to 820N are used. The diaphragm of the acoustic horn deflected 0.5 mm when a pressure of 552kPa was applied. It was further found that for as long as the diaphragm does not deflect and bleed the air the stress needed will be 816 MPa which will not reach the expected maximum. This will make the acoustic horn experience a pressure of 50MPa which is able to dislodge soot on the tube walls and surfaces of the boiler. This paper also looks at material and their properties which are used for the beam and acoustic horn.

Keywords:
SASOL, power plants, boilers, Design, Acoustics, maintenance, soot blowers.

1. Introduction

The first boiler that was developed was a kettle-type boiler in the 1700s and 1800s which simply boiled water into steam (Insolation, 2018). Fire tube boilers was one of the first boilers designed which consisted of the water surrounding the tubes in the shell of the boiler while fire runs through the tubes (Rite boilers, 2018). The fire-tube boiler has doors that swing open to clean the boiler tubes. This was an important feature for boilers fired with coal and wood (Babu, 2016). This proved to be very dangerous once boilers started becoming popular. This led to different methods of cleaning boilers, such as acoustic horn cleaning and water jet cleaning, soot blowing etc., to be developed. Fire-tubes are straight tubes that are rigid enough not to allow any expansion (Shandu et al, 2019). An acoustic horn or waveguide is a tapered sound guide designed to provide an acoustic impedance match between a sound source and free air, see Figure 1. This has the effect of maximizing the efficiency with which sound waves from the source are transferred to the air. Conversely, a horn can be used at the receiving end to optimize the transfer of sound from the air to a receiver. A boiler is a closed vessel in which fluid (generally water) is heated, as in Figure 2. The fluid does not necessarily boil. The heated or vaporized fluid exits the boiler for use in various processes or heating applications, including water heating, central heating, boiler-based power generation, cooking, and sanitation (Shandu, 2021). At present the firm uses soot blowers or cleaning of the interior of the boiler tubes, which as its own disadvantages (Holmes et al, 1999; Warriner and Noblett, 2002). Acoustic cleaning is a maintenance method used in material-handling and storage systems that handle bulk granular or particulate materials, such as grain elevators, to remove the build-up of material on surfaces. Acoustic cleaning apparatus, usually built into the material-handling equipment, works by generating powerful sound waves which shake particulates loose from surfaces, reducing the need for manual cleaning. Most acoustic cleaners operate in the audio frequency range from 60 hertz (Hz) up to 420 Hz. However, a few operate in the infrasonic range, below 40 Hz, which is mostly below the human hearing range, to satisfy strict noise control requirements.

Figure 1: A picture of an air horn used for cleaning (Rite boilers, 2018).

There are three scientific fields which converge in the understanding of acoustic cleaning technology these are materials science, surface friction and distance and areas. An acoustic cleaner will create a series of very rapid and powerful sound induced pressure fluctuations which are then transmitted to the surfaces where solid particles of ash, dust, granules or powder rest. This causes them to move at differing speeds and then bounce from adjoining particles and the surface that they are adhering to. Once they have been separated the material will fall off due to gravity or it will be carried away by the process gas or air stream. The key features which determine whether an acoustic cleaner will be effective for any given problem are the particle size range, the moisture content and the density of the particles as well as how these characteristics will change with temperature and time. Typically, particles between 20 micrometers and 5 mm with moisture content below 8.5% are ideal. Upper temperature limits are dependent upon the melting point of the particles and acoustic cleaners have been employed at temperatures above 1000 ^{o}C to remove ash build-up in boiler plants. The introduction of acoustic cleaners has been a significant improvement in many areas of health and safety. For instance, in silo cleaning - the previous solutions tended to be intrusive or destructive. Air cannons, soot blowers, external vibrators, hammering or costly man entry are all superseded by non-invasive sonic horns. An acoustic cleaner requires no down time and will operate during normal usage of the site (Shandu et al, 2018).

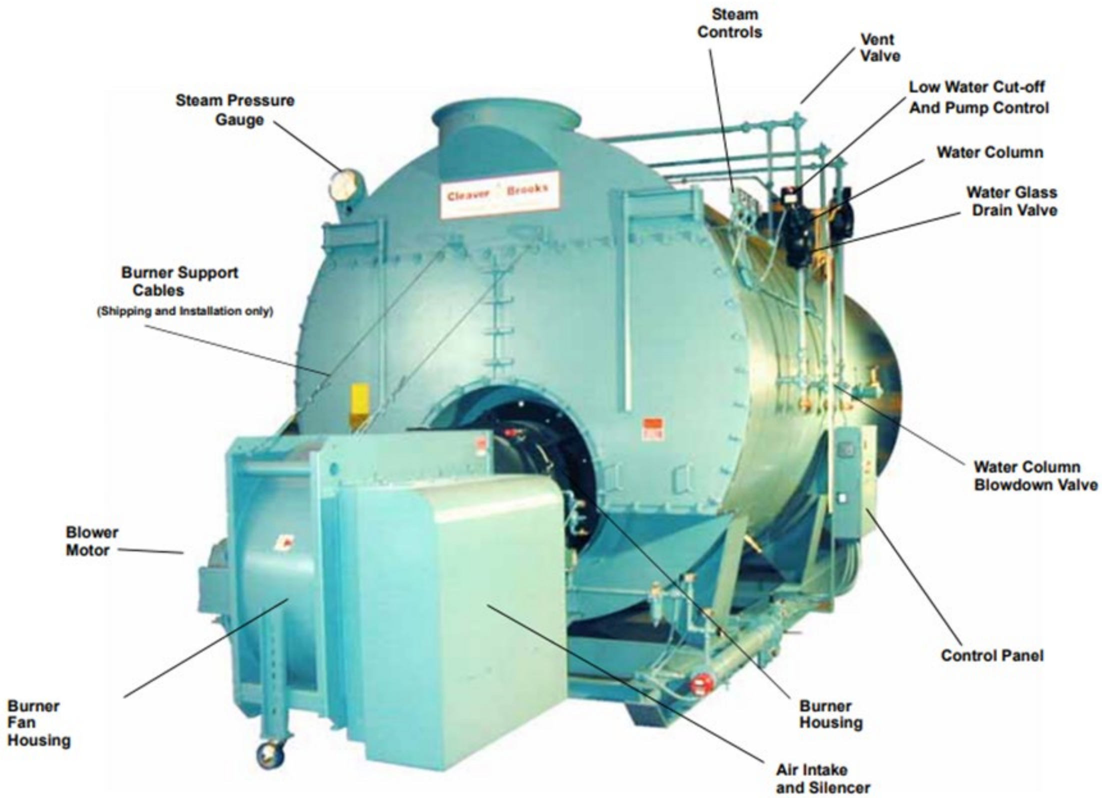

Figure 2: Picture of a Typical Boiler (Babu, 2016)

2. Design and Simulation of Model

The simulation was done using different forces acting on the beam which were 40N, 80N, 160N, 220N, 225N, 440N and 820N. The simulations showed the frequency produced at a specific force. This allowed the use of similarity law to find the frequency in the beam for which the horn will cause a frequency of 75Hz. In Figure 3, a simple beam is simulated in Autodesk Inventor 2016.

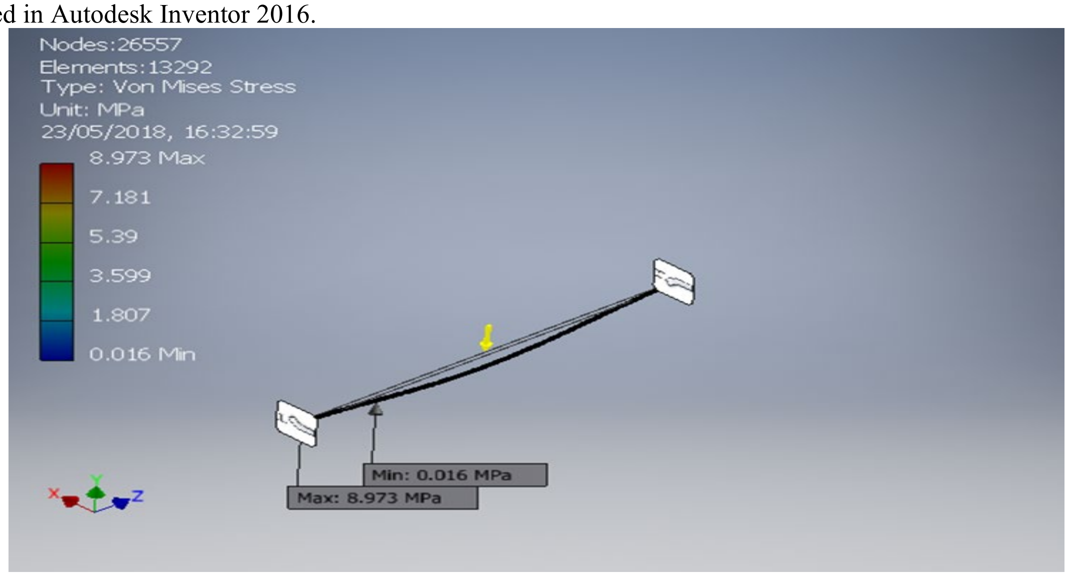

Figure 3: Figure showing how all simulations were run on inventor.

3. Similarity Law and Materials

An example of calculations carried out using this laws and values from Table 1 are shown here.

45.8N=13.47Hz

$$\therefore 75Hz\ would\ exert$$

$$\frac{45.8}{13.47} = \frac{x}{75}$$

$$x = 253.139N$$

Table 1: Material properties from Inventor professional

Name	**Iron, Cast**	
General	Mass Density	7.15 g/cm^3
	Yield Strength	758 MPa
	Ultimate Tensile Strength	884 MPa
Stress	Young's Modulus	120.5 GPa
	Poisson's Ratio	0.3 ul
	Shear Modulus	46.3462 GPa
Part Name(s)	Final Design	

4. Simulations

Figures 4 to 6 show the output from the simulations. The displacement ultimately shows that the beam will bend when the force of the horn is applied on the beam. It is assumed that the same displacement will occur in the opposite direction. The stresses and factor of safety shows that the beam is both safe and not in a dangerous region which is indicated by the low stress region. The stress will intensify as it approaches the center of the beam because that is where the maximum moment and force will be applied. A summary table for all the forces is illustrated on Table 2.

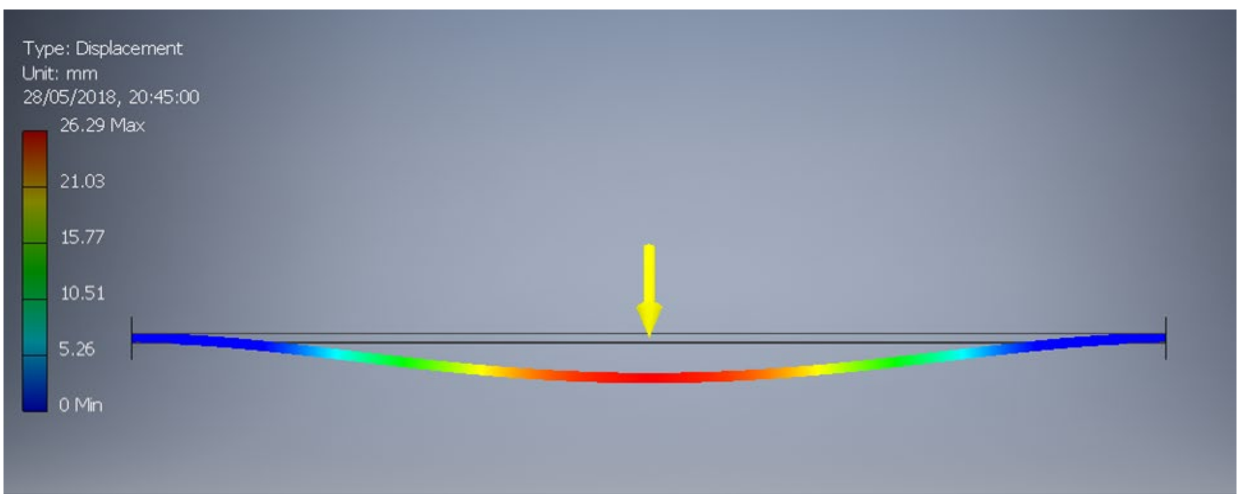

Figure 4: Displacement profiles.

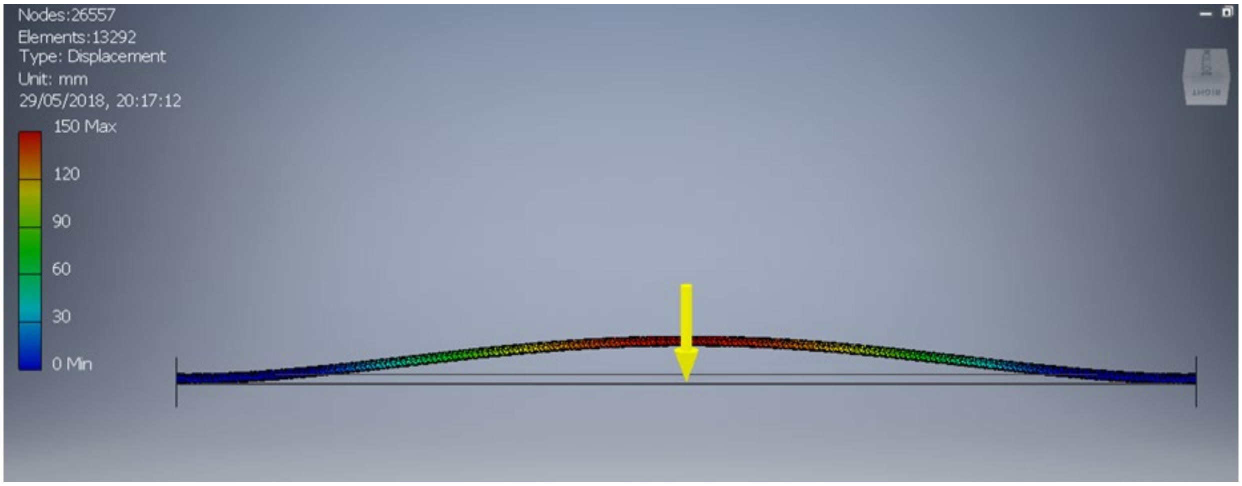

Figure 5: Von Mises Stresses.

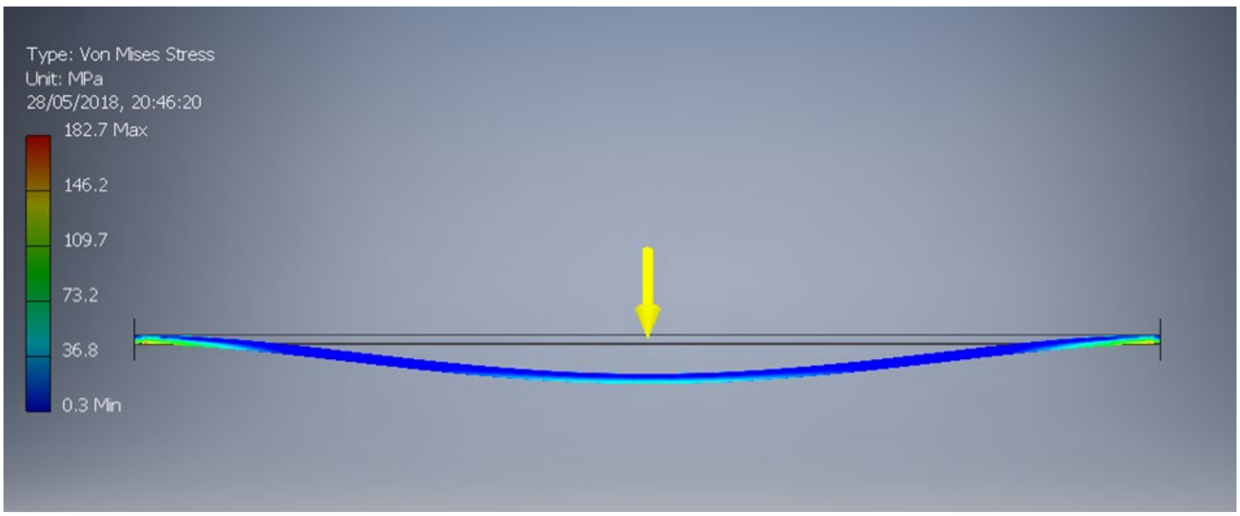

Figure 6: The beam while vibrating.

Table 2: Simulation Outputs Summarized

Mass (kg)	Magnitude of the Force (N)	Displacement (mm)	Von Mises Stress (MPa)
4.63287	40	1.12243	Min=0.0155278 Max=8.97296
	80	2.50447	Min=0.0244786 Max=17.9196
	220	7.0272	Min=0.0843262 Max=48.1572
	225	9.24558	Min=0.118846 Max=61.1562
	440	17.6772	Min= 0.0955168 Max=1 18.298
	820	26.2866	Min=0.312611 Max=182.653

The frequency from the horn generates a force that will "hit "the beam causing the bean to vibrate. The beam will be under a bending force which causes a deflection. The calculations show that the force of 253.139N will induce vibration in the beam with a horn frequency of 75Hz. The natural frequency established in the calculations show that the beam will start to vibrate at a frequency of 70Hz therefore the horn frequency is sufficient /strong enough to remove slag. The direct method in summarized in Table 3. The calculations show similar deflection to the simulated values as summarized in Table 2.

It was found that the best force to resonate the beam is the 225N because beyond that the beam may be damaged. Any force greater than 500N will be dangerous to the beam. The beam is set to be working with a factor of safety of 2 to compensate for any increase in stresses more than the defined working stress. This will give the safety assurance of the beam and maintain its stability throughout. The working stress is defined below the allowable stress due to the 225N force.

Table 3: Calculated Values Summarize

Mass (kg)	Magnitude of the Force (N)	Displacement (mm)	Stress (MPa)
4.6.3287	40	2.1024	Max=10.9329
	80	4.203	Max=21.86
	220	11.57	Max=60.13
	225	11.82	Max=61.479
	440	23.12	Max=120.22
	820	43.088	Max=224.06

5. Discussion

The graph in Figure 7 shows direct proportionality of both the calculated values and simulated values, they are both linear positively. Figure 7 shows that the stress and deflection calculated showed a maximum deflection of 26.2866mm for the simulated and 43.088mm for calculated values at the maximum force of 820N as per tables 3 for simulations and for calculated results.

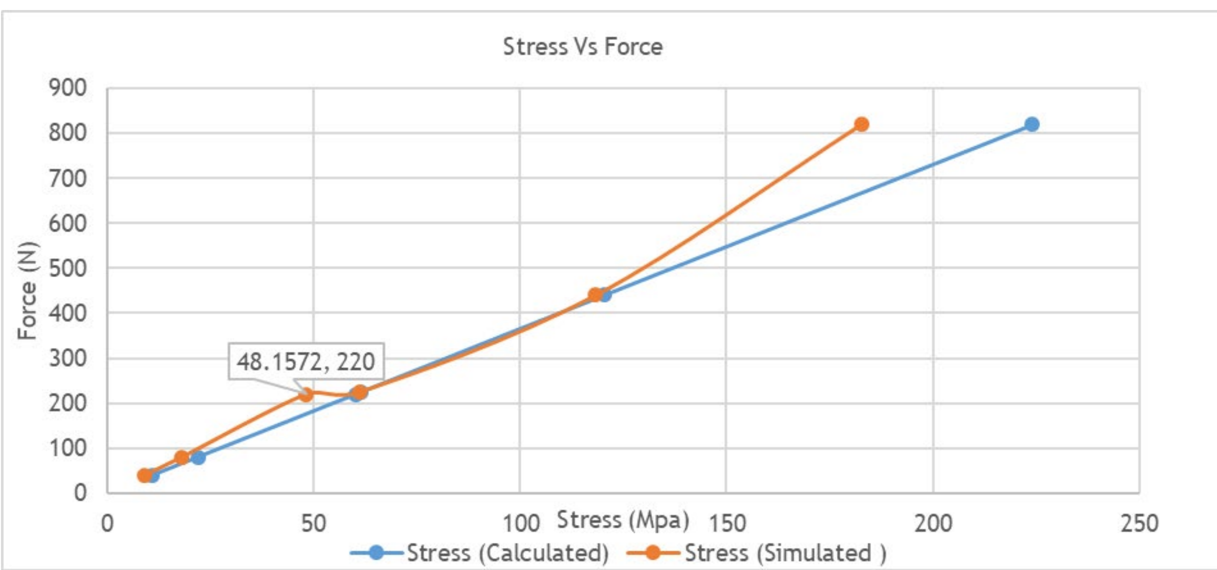

Figure 7: Stress Vs Force.

The figure shows statistical correlation between simulated and calculated values for forces of 220 N to 440 N. Th simulated stresses then diverge and show marked upward trends. This same trend is observed for the displacement curves in Figures 8 and 9.

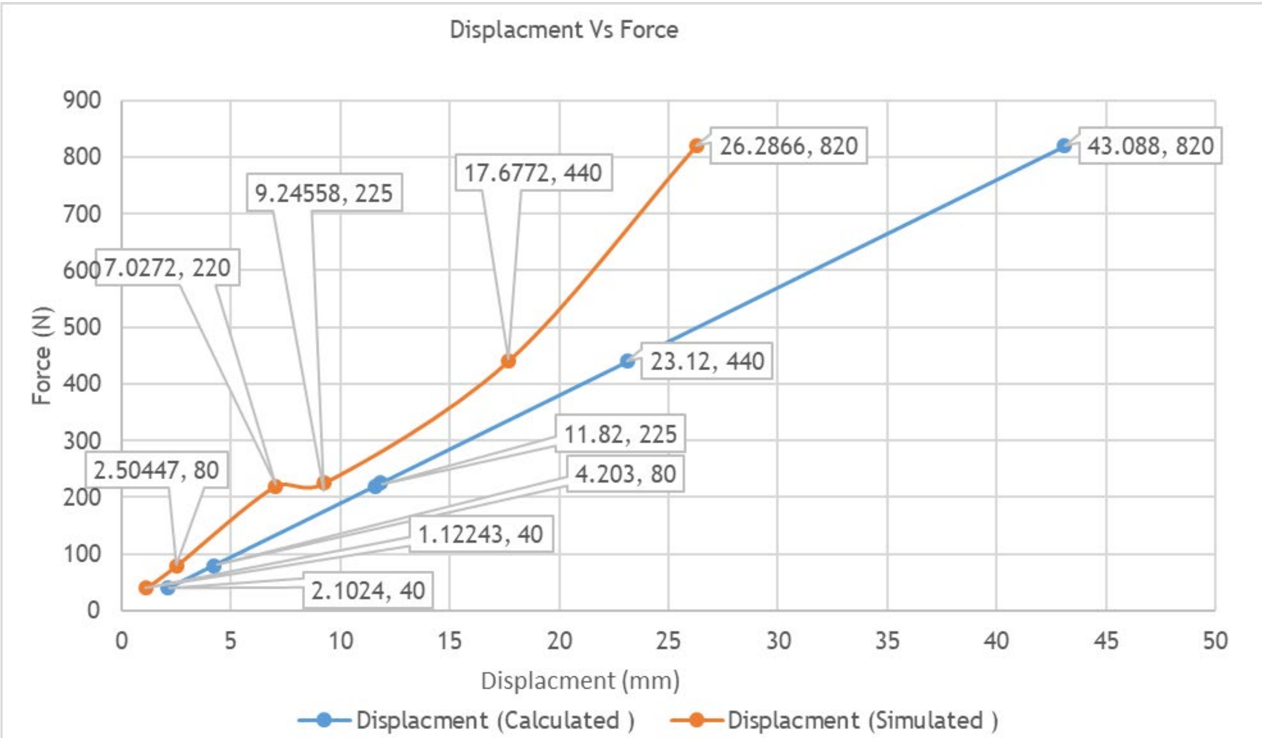

Figure 8: Displacement Vs Force.

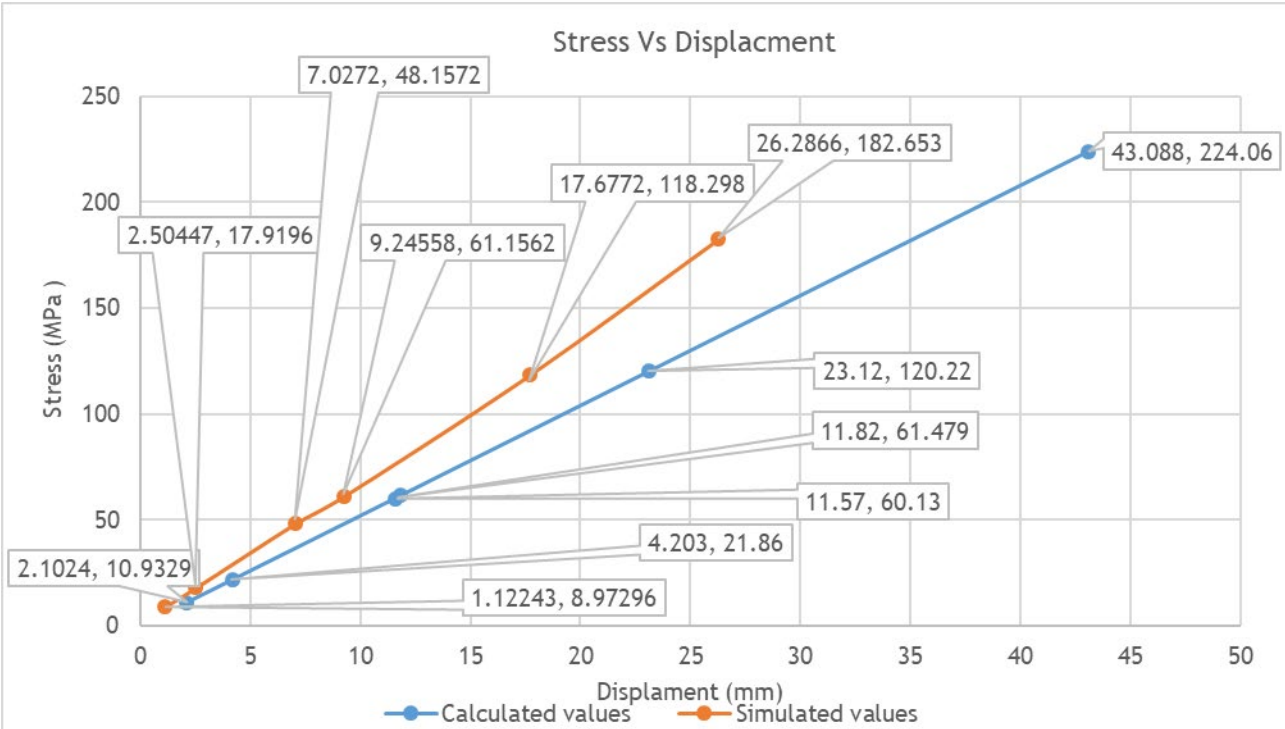

Figure 9: Stress Vs Displacement.

The simulation results represented by the deflection and the stress show how a vibrational force applied to a beam generates a waveform that affects the beam, removing slag. Figure 8 shows that when the beam is vibrating it may reach the same deflection in the upward direction. Figure 8 shows the relationship between the force and displacement when compared the graph in Figure 9. Figure 7 can also represent a stress-strain graph because strain is calculated from displacement. The graphs in these figures show a fracture point for simulated values and not for the calculated values because the values calculated do not take into consideration all three principal stresses and thus not giving an accurate value whereas in simulation the program takes inconsideration the strain caused by the force (Shandu, 2021).

In comparison of the two approaches it is found that the simulation approach is very fast, easy and gives a broader view of how the forces interact with the body. This interaction can be seen visually and can be easily interpreted. This approach can be very effective when solving most complex situations. This approach is fast and still has a high accuracy. The manual calculations take a long time to complete and does not look at the problem in complete detail as the simulation rather it looks at the direct effect the force will cause. This approach is not as accurate as it involves human error and rounding off values.

6. Conclusion

The material that was selected was appropriate for the project as cast-iron beams today are used in boilers. The cast iron beam, even though it is a brittle material, can still withstand high temperatures and a considerably high amount of vibration before fracturing. Brittle material was chosen because under high temperature ductile material will tend to expand drastically before fracturing and that is not good for the flow of water and fire moving through the tubes. The location of the stress in the simulation was correct as the stress was maximum where the force was applied. The maximum stress of 182.088MPa and a maximum deflection of 26.2866mm for the simulated values and with direct calculating of stress we get a max stress of 224.06MPa and deflection of 48.088mm. This deflection is enough to remove the slag and soot off the beams. The best force was found to be 225N which gave a max stress of 61.1562MPa and deflection 9.24mm. Based on the results obtained from the simulation and calculation, the applied force increases deflection as the stress approaches fracture (Shandu et al, 2019). However, the graphs and calculations showed that the maximum safe stress is 225N but can withstand values above this frequency. This allows the beam to vibrate without fracture under the 75Htz therefore it is concluded that the beam is safe for the operation as it will produce enough vibration to remove slag.

This paper discusses the merits of using an acoustic cleaning solution to maintenance industrial boilers. It is focused on the power industry and as such its contribution is in the area of maintenance of boiler used in the power industry. These boilers produce steam that are used to generate electricity via steam turbines.

7. ACKNOWLEDGEMENT

We would like to acknowledge that Sasol Africa funds this research through its Sasol-University Research Grant scheme.

8. REFERENCES

B. BABU. (2016). Design And Fabrication Of Pressing Steam Boiler. International Journal of Current Trends in Engineering & Research, 2(4), pp. 461 - 473.

R. Holmes, X. Faucher, and C. Silvester, "*Demonstration of an Advanced Sootblowing Control System*, Case Study: Application of Intelligent Sootblowing at PowerGen's Kingsnorth Power Station,," EPRI, Palo Alto, CA PowerGen, Nottingham,, UK, 1999.

Insulation, "The History of the Steam-generating Boiler and Industry," 2011. [Online]. Available: https://insulation.org/io/articles/the-history-of-the-steam-generating-boiler-and-industry/. [Accessed 28 May 2018].

Rite Boilers , "*A Brief History on Boilers*," 2012. [Online]. Available: http://www.riteboiler.com/index.php/pages/boiler-history. [Accessed 28 May 2018].

P.M. Shandu, D.V.V. Kallon, L.K. Tartibu, & R. Mutyavavire: Development Design of an Acoustic Cleaning Apparatus for Boilers at SASOL Synfuels Power Station Plant in Secunda. *Proceedings of the 11th South African Conference of Computational and Applied Mechanics* (SACAM). 2018. Pp 900 – 909.

P.M Shandu. Development Design of an Acoustic Cleaning Apparatus for Boilers at Sasol Synfuels Power Station Plant in Secunda. A dissertation submitted to the University of Johannesburg, 2021.

G. Warriner & Jim Noblett, Intelligent Sootblowing within a Global Intelligent Operations. *EPRI, CA*, 2002.

Biographies

Purity Mimi Shandu is an Energy and Demand Management Engineer at Airports Company South Africa (ACSA), and a PhD candidate at the University of Johannesburg, Gauteng, SA. She earned MTech and BTech in Mechanical Engineering from University of Johannesburg, Gauteng and a National Diploma in Mechanical Engineering from Mangosuthu University of Technology, KwaZulu Natal, SA. She holds a higher certificate in Production, Operations and Proactivity Management form the University of South Africa (UNISA). She has published an article for conference proceeding, at the 11th South African Conference in Computational and Applied Mechanics. Her research interests include power generation, simulation, optimization, reliability, scheduling, manufacturing, and energy management systems. She is registered as a candidate with the department of labor towards obtaining her Government Certificate of Competency (GCC) ticket and has a candidacy membership with Engineering Council of South Africa (ECSA). She is a nominee for International Executive Development Programme (IEDP) 2020/2021, an initiative by Transport Education Training Authority (TETA) in partnership with Gordon Institute of Business Science, to train highly skilled, competitive and competent people in the various facets of the transport sector (Rail, Aerospace, Maritime, Road Freight, Road Passenger, Taxi, FreighHandling and Forwarding & Clearing.

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 Dr Kallon 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 from Masters to Postdoctoral and has graduated seven (7) Masters Candidates. Dr. Kallon's primary research areas are Acoustics Technologies, Mathematical Analysis and Optimization, Vibration Analysis, Water Research and Engineering Education.