Mitigating Resonant Vibration via Compressor Base Frame redesign at Souq Al-Khamis Cement Factory, Libya (Part II)

Ahmed Omran1
Mechanical and enrgies Production dep
Libyan Academy for Postgraduate Studies
Souq Al-Khamis cement factory, Ahlia Cement Company
Tripoli, Libya
ako530137@gmail.com

Osama Hassin
Mechanical and enrgies dep
Libyan Academy for Postgraduate Studies
Tripoli, Libya
osama.hassin@academy.edu.ly

Mostafa Abobaker
Mechanical and enrgies dep
Libyan Academy for Postgraduate Studies
Tripoli, Libya
ae.messuri@academy.edu.ly

Abdulhafid Elfaghi
Mechanical and Manufacturing Engineering dep
Universiti Tun Hussein Onn
Pagoh Johor, Malaysia
abdulhafid@uthm.edu.my

Sadok Sassi
Mechanical and industrial dep
University, Qatar
Doha, Qatar
sadok.sassi@qu.edu.qa

***Abstract*—Resonance occurs when the operating frequency of a system aligns with its natural frequency, resulting in amplified vibration amplitudes. To prevent potential damage and ensure optimal performance of a compressor's base frame at Souq Al-Khamis Cement Factory, researchers found the resonance in has been occurred when both the natural frequencies and rotating frequency were overlapped. Resonant Vibration in the base frames arises when the rotating vibration frequency aligns with the frame's natural modes that leads to structural instability, fault unplanned shutdowns and production losses. This study analyzes resonant vibration in a cement factory compressor base frame and proposes a redesign using finite element methods to mitigate this issue. Four distinct modifications were made to the base frame on its shape, weight and boundary conditions: the first introduces fixed points to enhance rigidity, the second adds supports for increased stability, the third incorporates elements to improve durability, and the fourth enhances the thickness of the compressor. The results indicate that the redesigned configuration most effectively mitigates resonance and improves the system's natural frequency response.**

Keywords—Resonance, Compressor Base Frame, Redesign, Natural Frequency, Finite Element Analysis.

1 Introduction

Rotary machines are used in industrial fields such as the cement industry. Improving the performance and ensuring the operational efficiency of these machines is an ongoing endeavor. At the Souq Al Khamees Cement Plant, one of the critical challenges that often arises is the occurrence of resonance in the cement mill compressor systems. Resonance, a phenomenon in which vibrations are amplified by the system's natural frequency, can lead to adverse effects such as increased wear, reduced equipment life, and decreased productivity.

Studies on the issues of high vibration and low reliability of different kinds of machinery during operation have been conducted recently [1][2]. The resonance occurs when an external force resonates with a structure's inherent frequency, it is referred to as mechanical resonance. This resonance frequency is usually cognizant of the structure's natural frequency and produces a significant vibrational amplitude at it [3][4][5]. Tong et al. performed a finite element modal study of a core stub collector's frame using ANSYS Workbench software [6]. They were able to get the frame's first ten natural frequencies and vibration modes and managed to determine the dynamic properties [6].

Studying a mechanical structure's vibration properties involves designing it to have a natural frequency that is far away from the excitation frequency. This effectively prevents resonance and lessens damage [7]. To ensure that the base frame is built as it is and retains its integrity, the compressor's base frame requires effective design and technology. The compressor must optimize the life of the base frame while working under this load. Standard beams or channel sections are what a foundation frame is typically made of. Yang, P. A. Salunkhe discusses the construction and modeling of a base frame for a multi-compressor pack [8].

Liu et al. simulated the mode and deformation of the crankshaft under various counterweight circumstances using finite element analysis software, and by installing alternative counterweights, the engine's vibration amplitude was successfully reduced[9].

Based on our previous study [10], which showed that vibrations were mainly caused by resonance when the compressor's rotation matched its natural frequency, this study focuses on improving the base frame design. Four modified geometries are developed and analyzed using finite element analysis in ANSYS Workbench. The goal is to find a design with a natural frequency outside the operating range, so resonance can be avoided and the system can run more smoothly and reliably.

Resonance in mechanical systems can sometimes lead to undesirable effects such as excessive vibrations, noise, or even structural failures. common methods for reducing resonance include remove the excitation, reduce the excitation, increase the resonant frequency, decrease the resonant frequency, dynamic absorbers and reduce the time at resonant frequency. In this research Resonance reduction strategies may be put into practice by changing the compressor's base frame structures and its boundary conditions

2 Methodology

Based on the study conducted by researcher on one of the compressors at Souq Al-Khamis Cement Factory, the study revealed a coincidence between the sixth mode shape and the

DOI:10.5281/zenodo.15394556

excitation frequency of the compressor's speed, which causes a resonance phenomenon. To solve this problem, this study aims to redesign the compressor's base using several designs and select the optimal design among these designs to avoiding resonance. The base frame has been designed by SolidWorks, and then a FEM analysis has been executed in the ANSYS Workbench [10].

To avoid resonance, the redesigns introduced various modifications to the original base frame. These modifications included adding installation points, incorporating supports, and increasing the thickness of specific areas. These changes aim to alter the natural frequency of the base frame, ensuring that it does not align with the frequency of the compressor vibrations.

The original design of the base frame was that the total mass of the compressor system, with all components, was estimated at 1481 kg. The model incorporated 8 bolts securing the base frame foundation, with zero degrees of freedom at each of the bolt holes. The base frame geometries were dimensions of 2400 mm length, 800 mm width, and 200 mm height as shown Fig. 1 and Fig. 2.

Fig. 1. Compressor component

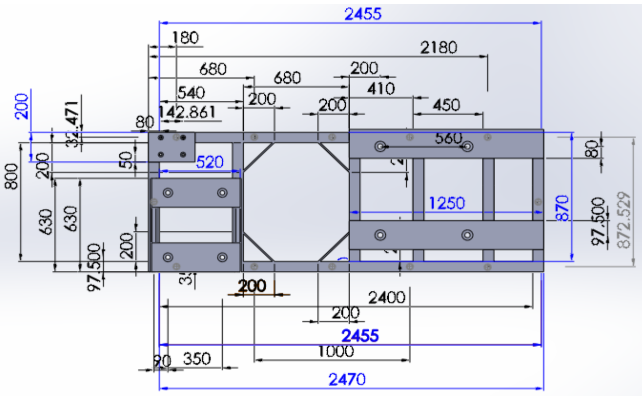

Fig. 2. Compressor’s base frame geometric details

The original design of the base frame was installed on a base frame that was designed in the workshop without a study. When a base frame is designed without considering the dynamic properties of the equipment it supports. Diagnosis of high vibration causes by resonance when overlapping frequencies were happened between natural frequencies of base frame and the forcing frequencies generated by the compressor's operating speed and its harmonics. The aim was identified a potential match between the structure's resonant frequencies and the input vibration frequencies.

In Fig. 3, a dashed circle was used to highlight the correspondence between the sixth mode natural frequency of 115.9 Hz and the excitation frequency of 123.217 Hz (red horizontal line) generated by the compressor's rotating speed. Other two horizontal lines (blue and green) indicated the first and second harmonic of rotating frequencies (1x123, 2x 123.217) respectively. This finding indicates a significant alignment between the resonant frequency of the structure and the input vibration source. In this case, the observed vibrations are likely caused by resonance due to the matching of the structure's sixth mode natural frequency and the compressor's excitation frequency.

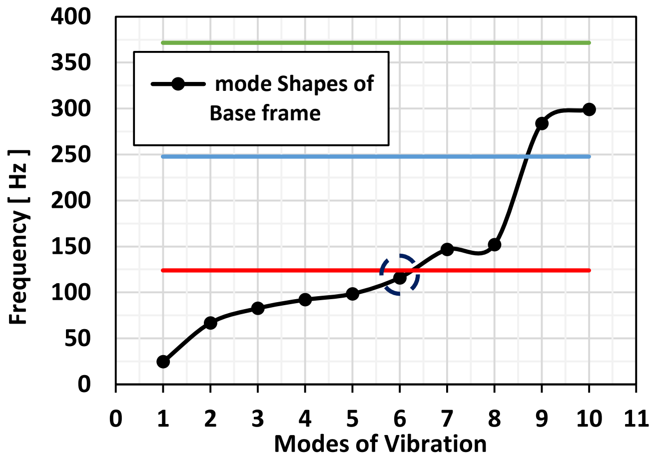

Fig. 3. Compressor's excitation frequencies and modal shape frequencies

The studies provide four case studies on the design and analysis of compressor base frames to avoid original and innovative resonances. The redesigns introduced various modifications to the original base frame. These modifications included adding installation points, incorporating bracing, and increasing the thickness of specific areas. These changes aim to alter the natural frequency of the base frame, ensuring that it does not align with the frequency of the compressor vibrations, as seen in خطأ! لم يتم العثور على مصدر المرجع.

TABLE I. RESEARCH METHODOLOGY PLANS

Phases	Part I [10]	Part II			
Aim	Diagnose the problem	Solve the problem			
Description	Vibration at compressor's base frame at Souq Al-Khamis Cement Factory	added fixed points to compressor base frame	added supports beams to the base frame structure	Design I + Design II	increasing base frame thickness at where deformation increased
Research Methodology	Measuring & calculation the rotating frequency that transferred to base frame				
	Ansys Simulation FEM analysis to obtain mode shapes of the base frame (Node 849200, elements 471866, type of element; Tetahedral10)				
Analysis method	Comprising between frequencies				
In search of	non-matching between the frequencies				

The first design added fixed points to the compressor base frame, as shown in Fig. 4. This provided a strong and rigid structure to reduce vibration and noise, allowing for a more efficient operation.

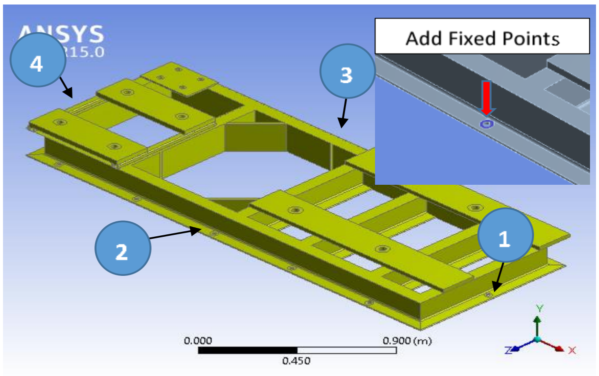

Fig. 4. The first redesign (fixed points)

The second redesign added supports beams to the base frame structure, as shown in Fig. 5. This way, the compressor base will be more stable and less likely to move when the compressor is turned on. The supports will also help to absorb the shock of the compressor when it is operating, preventing it from vibrating excessively.

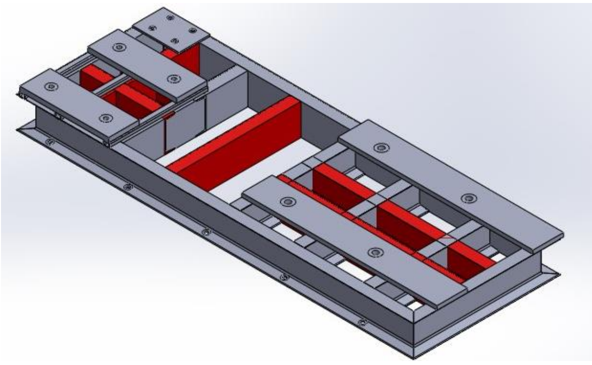

Fig. 5. The second redesign, with adding supports to main base frame

The third redesign was made to the compressor base by combining the elements of both the first and the second designs. By implementing the installation points from design 1 and the supports from design 2, this design aims to maximize the stability and durability of the compressor base. The combined configuration is illustrated shown in Fig. 6.

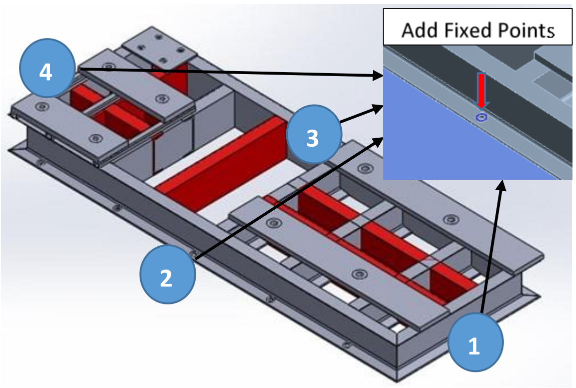

Fig. 6. The third redesign (fixed points and support beams)

The fourth redesign were made to the second design. Specifically, the thickness of the area where the original compressor base frame deformation was increased in Fig. 7 [10]. The modified configuration design can be shown in Fig. 8

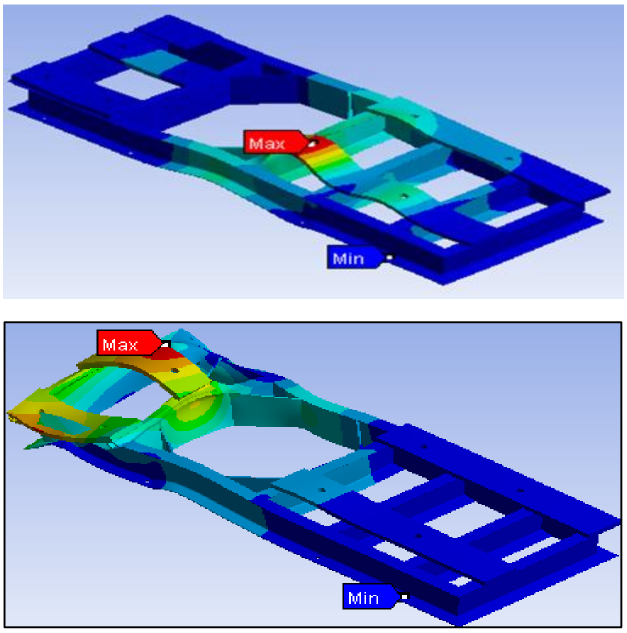

Fig. 7. Deformation of original base frame a) mode shape 4, b) mode shape 6 [10]

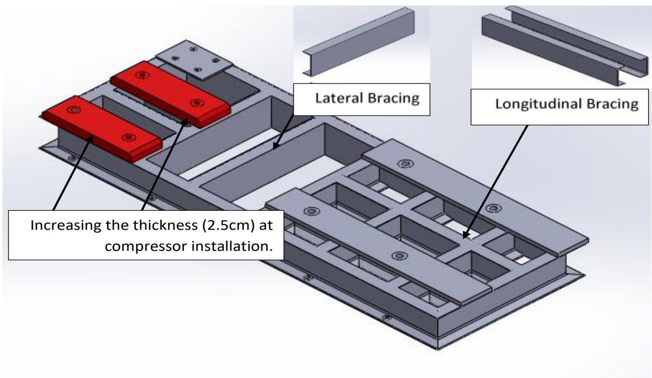

Fig. 8. Fourth redesign with supports and increasing thickness at compressor installation area

3 Results and Discussion

In the original design, the results indicated that the natural frequency of the sixth mode was approximately 115.9 Hz, which was in close proximity to the excitation frequency of rotating speed 123.84 Hz. This proximity led to the occurrence of resonance, a phenomenon that arises when the excitation frequency matches or is near the natural frequency of the base frame. Resonance amplifies vibrations and can have potentially detrimental effects [10].

In the first design, as illustrated in خطأ! لم يتم العثور على مصدر المرجع. alterations in the natural frequencies of the compressor base frame were observed. However, these changes did not fulfill the desired criteria for breaking out of the state of resonance, particularly in the sixth mode shape.

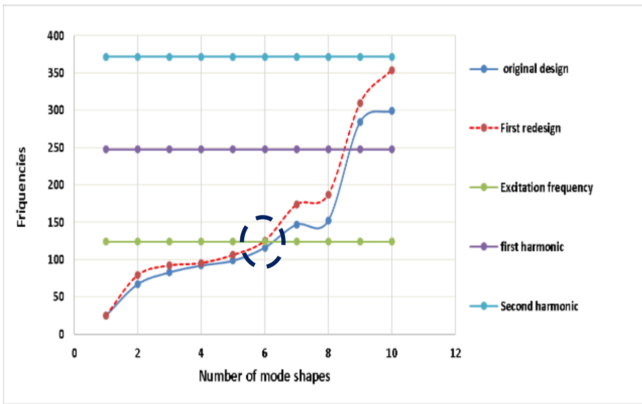

Fig. 9. Mode shapes vs excitation frequencies of 1st design and original design

However, in Fig. 9 and Fig. 10, respectively, it is important to note that both the second and third redesigns showed instances of mode coupling, where the third and fourth modes coincided with the excitation frequency. Additionally, the tenth mode of the third design coincided with the second harmonic of the excitation frequency at the compressor speed.

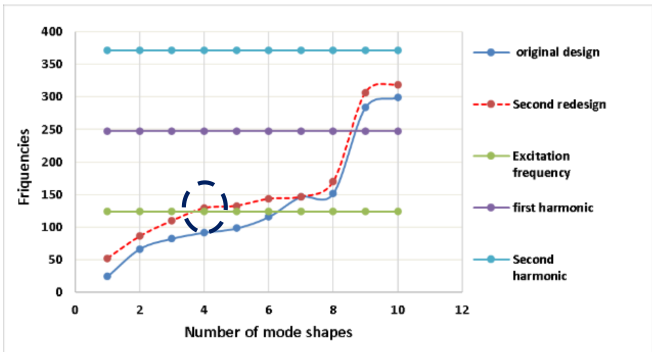

Fig. 10. Mode shapes vs excitation frequencies of 2nd design and original design

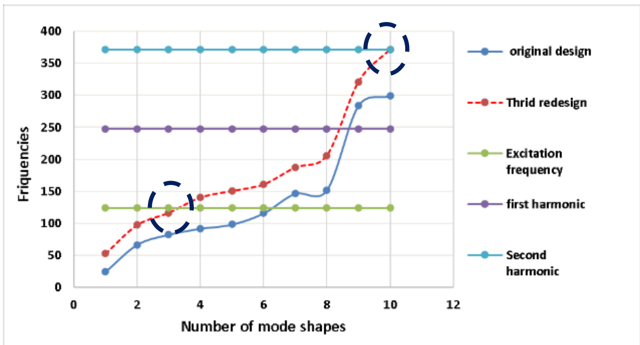

Fig. 11. Mode shapes vs excitation frequencies of 3rd design and original design

To mitigate the resonance phenomenon in this study, modifications were made to the original design. The results, as demonstrated Fig. 11 depicting the fourth redesign, revealed an enhancement in the natural frequency of the sixth mode shape, increasing it from 115 Hz to 140 Hz. Similarly, the second and third redesigns also exhibited significant improvements in the natural frequency of the sixth mode shape.

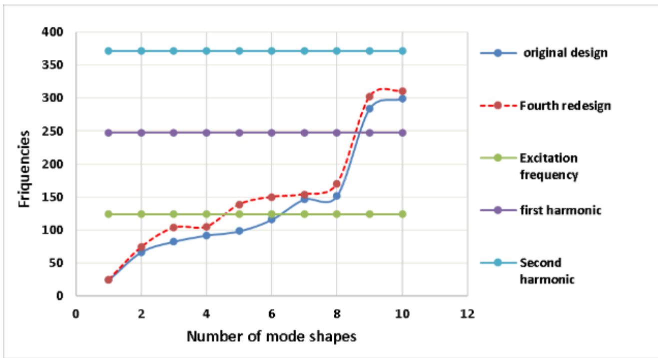

Fig. 12. Mode shapes vs excitation frequencies of 4th design and original design

The findings underscore the critical significance of careful design parameter adjustments in achieving the desired frequency responses and preventing resonance phenomena, which can have detrimental effects such as unwanted vibrations and potential structural failures. Based on the analysis of the different designs, in Fig. 12, fourth redesign illustrates the most successful redesign. This particular design involved increasing the thickness at the compressor installation area and incorporating support beams to enhance the stiffness of the system. As a result of this modification, a substantial improvement in the natural frequency of the system, particularly in the sixth mode shape, was observed. The increased thickness effectively mitigated resonance and contributed to improved overall performance and structural stability. Table II II presents the summary of all contribution of the research.

TABLE II RESEARCH METHODOLOGY PLANS

<table>
<tr><td rowspan="2">Part I [10]</td><td colspan="5">Resonance phenomenon has been Identified</td></tr>
<tr><td colspan="4">mode shape 6 = Rotating frequency</td><td>Fig. 3</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td rowspan="5">Part II</td><td colspan="5">Redesign the base frame to avoid the frequencies matching</td></tr>
<tr><td>Design I</td><td>added fixed points to the compressor base frame</td><td>Mode shape 6 = Rotating frequency</td><td>Resonance still exists</td><td>Fig. 9</td></tr>
<tr><td>Design II</td><td>added supports beams to the base frame structure</td><td>Mode shape 4 = Rotating frequency</td><td>Resonance still exists</td><td>Fig. 10</td></tr>
<tr><td>Design III</td><td>Design I + Design II</td><td>Mode shapes 3,10 = Rotating frequency</td><td>Resonance still exists</td><td>Fig. 11</td></tr>
<tr><td>Design IV</td><td>increasing base frame thickness at where deformation increased</td><td>Any Mode shapes ≠ Rotating frequency</td><td>No Matching Resonance avoided</td><td>Fig. 12</td></tr>
</table>

4 CONCLUSION

Achieving appropriate frequency responses and avoiding resonance in the cement mill compressor base frame are made possible by carefully adjusting design parameters. The study highlighted the importance of considering specific design parameters and adjustments to achieve optimal frequency responses and mitigate potential issues related to resonance. Through simulations and finite element analysis, researchers redesigned the object with fixed points, supports, and greater thickness and the outcomes were compared to the original design.

The results showed that the fourth redesign, which involved increasing the thickness at the compressor installation area and incorporating support beams, was the most successful in mitigating resonance and improving the natural frequency of the system. This modification enhanced the overall performance and structural stability of the compressor base. These findings emphasize the importance of considering specific design parameters, including thickness adjustments and the incorporation of support elements, to achieve optimal frequency responses and mitigate potential issues related to resonance.

References

[1] Z. Qin, Y. T. Wu, A. Eizad, K. H. Lee, and S. K. Lyu, "Design and evaluation of two-stage planetary gearbox for special-purpose industrial machinery," *J. Mech. Sci. Technol.*, vol. 33, no. 12, pp. 5943–5950, 2019, doi: 10.1007/s12206-019-1139-7.

[2] S. I. Moon, I. J. Cho, and D. Yoon, "Fatigue life evaluation of mechanical components using vibration fatigue analysis technique," *J. Mech. Sci. Technol.*, vol. 25, no. 3, pp. 631–637, 2011, doi: 10.1007/s12206-011-0124-6.

[3] S. Kreitzer, J. Obermeyer, and R. Mistry, "The effects of structural and localized resonances on induction motor performance," *IEEE Trans. Ind. Appl.*, vol. 44, no. 5, pp. 1367–1375, 2008, doi: 10.1109/TIA.2008.2002179.

[4] S. S. Rao, *Vibration of Continuous Systems*. 2007. doi: 10.1002/9780470117866.

[5] V. Sorokin and I. Blekhman, "On the stochastic resonance phenomenon in parametrically excited systems," *Eur. J. Appl. Math.*, vol. 30, no. 5, pp. 986–1003, 2019, doi: 10.1017/S0956792518000608.

[6] J. Tong, B. Zeng, D. Chen, L. Quan, and S. Zhang, "Finite element modal analysis of the frame of corn stubble-collector," *Adv. Mater. Res.*, vol. 430–432, pp. 1072–1075, 2012, doi: 10.4028/www.scientific.net/AMR.430-432.1072.

[7] S. Agrawal, N. Sherje, and A. Umbarkar, "Design and Analysis of Compressor Base Frame for Weight Reduction," *SSRN Electron. J.*, 2019, doi: 10.2139/ssrn.3350911.

[8] P. A. Salunkhe, G. Kulkarni, and M. Begad, "Static and Free Vibration Analysis of Multi-Compressor Packs Base," no. 4, pp. 161–171, 2016.

[9] B. Liu and H. L. Jiang, "Finite element modal analysis of S385 diesel engine block," *Appl. Mech. Mater.*, vol. 490–491, pp. 504–509, 2014, doi: 10.4028/www.scientific.net/AMM.490-491.504.

[10] A. Omran, O. Hassin, S. Sassi, and F. Gu, "Diagnosis of High Vibration Causes at the Screw Air Compressor Base Frame in Souq Al-Khamis Cement Factory (Part I)".