DEMOCRATIC REPUBLIC OF ALGERIA
MINISTRY OF HIGHER EDUCATION AND SCIENTIFIC RESEARCH

UNIVERSITY SAAD DAHLAB DE BLIDA 1
FACULTY OF TECHNOLOGY
Structural Mechanics Research Laboratory
Department of Mechanical Engineering

Project Graduation
For Obtaining the Master’s Degree In
Mechanical and Production Manufacturing

Vibration Monitoring and Mechanical Fault Diagnosis.

Centrifugal Finisher Pump Application

Proposed and supervised by:
Pr. Mohammed OUALI
Dr. Rabah MAGRAOUI

Realized by:
Sennoun Imad Eddine
Bougoffa Akram

College year 2024/2025

Vibration Monitoring and Mechanical Fault Diagnosis.

Centrifugal Finisher Pump Application

In mechanical engineering, especially in machine maintenance, vibration monitoring plays a critical role in ensuring optimal performance and extending equipment lifespan. It is essential for enhancing machine availability, enabling timely scheduling of repairs and balancing interventions, and detecting various mechanical faults.

The centrifugal finisher pump under consideration required vibration monitoring, which significantly improved its operational availability. Through this process, we were able to proactively schedule maintenance activities, such as repairs and shaft balancing.
Several mechanical defects were identified in the installation, including:

- Misalignment between the two motor shafts and the turbine shaft.
- Bearing faults in the turbine shaft, which resulted in frequent bearing replacements.

The repeated failure of the turbine shaft bearings highlighted the need to reassess and resize the bearings to better match the system’s operational demands.

These observed practical results will be compared with numerical analysis outcomes to validate findings and refine the design and maintenance strategies.

KEYWORDS: Vibration Monitoring, Mechanical Fault Diagnosis, Centrifugal Finisher, Numerical Analysis, Fault Detection.

مراقبة الاهتزازات وتشخيص الأعطال الميكانيكية
تطبيق على مضخة التشطيب الطردية

في الهندسة الميكانيكية، وخاصة في صيانة الآلات، تلعب مراقبة الاهتزازات دورًا حيويًا في ضمان الأداء الأمثل وإطالة عمر المعدات. تعتبر هذه المراقبة ضرورية لتحسين جاهزية الماكينات، وتمكين جدولة الإصلاحات وموازنة الأجزاء بشكل مناسب، بالإضافة إلى الكشف عن الأعطال الميكانيكية المختلفة.

تطلبت مضخة التشطيب الطردية التي تم دراستها مراقبة دقيقة للاهتزازات، مما أدى إلى تحسين كبير في جاهزيتها التشغيلية. ومن خلال هذه العملية، تمكنا من جدولة أنشطة الصيانة بشكل استباقي، مثل أعمال الإصلاح وموازنة العمود.

تم تحديد عدة عيوب ميكانيكية في التركيب، بما في ذلك
عدم محاذاة بين عمودي المحرك وعمود التوربين.
أعطال في محامل عمود التوربين، مما أدى إلى تكرار استبدال المحامل.

أدى تكرار فشل محامل عمود التوربين إلى الحاجة لإعادة تقييم وتصميم حجم المحامل بما يتناسب مع متطلبات التشغيل الفعلية للنظام.

سيتم مقارنة هذه النتائج العملية بالمخرجات العددية للتحليل بهدف التحقق من صحة النتائج وتحسين استراتيجيات التصميم والصيانة

الكلمات المفتاحية.:

مراقبة الاهتزازات، تشخيص الأعطال الميكانيكية، مضخة التشطيب الطردية، التحليل العددي، الكشف عن الأعطال

Surveillance des Vibrations et Diagnostic des Défauts Mécaniques
Application à une Pompe de Finition Centrifuge

En ingénierie mécanique, en particulier dans la maintenance des machines, la surveillance des vibrations joue un rôle essentiel pour assurer des performances optimales et prolonger la durée de vie des équipements. Elle est indispensable pour améliorer la disponibilité des machines, permettre la planification en temps opportun des réparations, des équilibrages, et détecter divers défauts mécaniques.

La pompe de finition centrifuge étudiée nécessitait une surveillance des vibrations, ce qui a considérablement amélioré sa disponibilité opérationnelle. Grâce à ce processus, nous avons pu planifier de manière proactive les activités de maintenance, telles que les réparations et l'équilibrage de l'arbre.

Plusieurs défauts mécaniques ont été identifiés lors de l'installation, notamment :

- Un désalignement entre les deux arbres moteurs et l'arbre de la turbine.
- Des défauts de roulements sur l'arbre de la turbine, entraînant des remplacements fréquents.

La défaillance répétée des roulements de l'arbre de la turbine a mis en évidence la nécessité de réévaluer et redimensionner les roulements pour mieux répondre aux exigences opérationnelles du système.

Les résultats pratiques observés seront comparés aux résultats de l'analyse numérique afin de valider les constats et d'optimiser les stratégies de conception et de maintenance.

MOTS-CLÉS : Surveillance des vibrations, Diagnostic des défauts mécaniques, Pompe de finition centrifuge, Analyse numérique, Détection des défauts.

Gratitude

First of all, we would like to thank Allah for granting us the health, willpower, and patience to complete our Master's degree and carry out this research. We would like to express our deepest gratitude to our supervisors, Mr. Magraoui and Mr. Ouali, who provided us with the topic for this dissertation and guided us with their valuable advice and suggestions, as well as for the trust they showed in us throughout this work.

We would also like to thank the members of the jury for their interest in our research by agreeing to review our work.

We would like to sincerely thank SPA AQUA SIM BLIDA and its maintenance teams for welcoming us and helping us develop this project.

We also thank all the professors in the Mechanics Department who contributed to our Master's program in Mechanical Engineering. Finally, we extend our sincere feelings of gratitude and appreciation to all those who participated directly or indirectly in the completion of this work.

Dedication

I dedicate this work to all those who made this project possible through their unwavering support, encouragement, and insightful guidance.

To my family
To my parents, for their unconditional love, moral and material support, and for always believing in me.
To my siblings, for their patience, kindness, and constant encouragement.

To my supervisors
For their outstanding guidance, valuable advice, and the trust they placed in me throughout this work. their direction and support were instrumental in the completion of this thesis.

To the members of the jury
For their availability, their valuable time, and their constructive feedback, which greatly contributed to improving the quality of this work.

To the institutions and collaborators
My sincere thanks to the SIM Group and its maintenance engineers for their warm welcome, invaluable assistance, and the resources they provided.

To my teachers
I extend my gratitude to all the professors of the Mechanical Engineering Department for their dedication and their essential contribution to my academic training in mechanical design.

To my friends and colleagues
For their support, friendship, and the moments we shared, which enriched this experience and helped me overcome many challenges.

To all those who contributed
Thank you to everyone who, directly or indirectly, played a part in the completion of this work through their support, advice, and encouragement.

Table of contents

Tables list:

Chapter II:

Chapter III:

Chapter IV:

Chapter I:

Chapter II :

Chapter III :

.

Chapter VI :

Chapter I : INTRODUCTION

1. Introduction

1.1 Vibration Analysis and Maintenance of Rotating Machines:

Rotating machines are central to industrial processes, from energy production to manufacturing and transportation. These machines include everything from massive turbines in power plants to smaller motors on production lines, all converting energy in various forms for numerous industrial applications. However, their complex mechanical and electrical systems are prone to various issues, significantly impacting productivity and profitability [1].

1.1.1 Importance of Vibration Analysis in Rotating Machinery:

Mechanical failures are a constant challenge for rotating machines. Issues such as imbalances, misalignment, and bearing failures lead to excessive vibrations, resulting in component fatigue and catastrophic failures. Uncontrolled vibrations can propagate through the machine and its supporting structure, causing extensive damage. Furthermore, lubrication problems such as contamination, degradation, and insufficient supply accelerate wear and reduce machine lifespans [2].

1.1.2 Key Vibrational Issues :

- Imbalance (Defective Balancing): Always present to some extent due to manufacturing imperfections. Leads to increased vibrations and wear.
- Misalignment: A Significant cause of equipment life reduction, occurs with angular or radial misalignment between two connected shafts.
- Insufficient Fastening: Poor fastening of the machine structure generates noise and reduces lifespan.
- Bearing Defects: Common issues include spalling, seizing, corrosion, which all lead to significant machine wear.

1.1.3 Maintenance Strategies for Rotating Machines:

Given the significant dependence on rotating machines, robust maintenance strategies are essential. Unplanned downtime due to machine failure results in financial losses, production delays, and potential safety risks. Modern predictive maintenance, leveraging technologies like vibration analysis, infrared thermography, and oil analysis, facilitates early problem detection, enabling swift interventions and minimising downtime [3].

1.1.4 Predictive Maintenance Approaches :

Modern industrial systems increasingly incorporate advanced monitoring systems, including sensor networks and data analytics, for continuous machine condition evaluation and performance optimization. These systems provide real-time insights into operating conditions, allowing for proactive maintenance and ensuring reliability and efficiency.

1.2 Types of Industrial Pumps and Their Failures:

Understanding the different types of pumps and their potential failures is crucial for effective maintenance. Two main categories of pumps are commonly used: dynamic pumps (e.g., centrifugal pumps) and positive displacement pumps (e.g., piston pumps).

1.3 Centrifugal Pump Components: [2], [L1]and[L2]

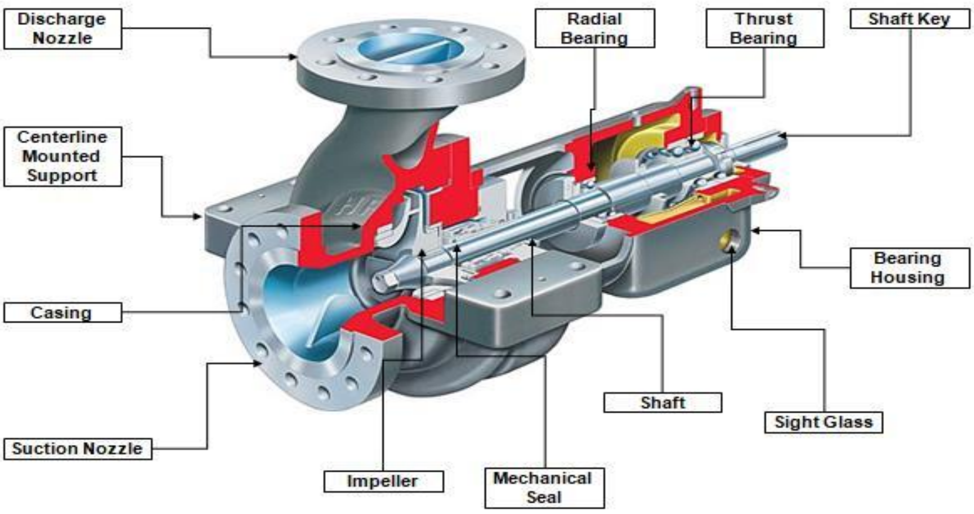

FIGURE 1-1: Centrifugal Pump

Centrifugal Pump Overview

Centrifugal pumps come in a wide range of designs, from simple models with just a few components to highly complex systems consisting of hundreds of individual parts. Despite the variations, some components are commonly found in most centrifugal pumps, including **wearing rings**, **stuffing boxes**, **packing**, and **lantern rings**.

Key Components and Their Functions:

- **Impeller**: The impeller features rotating vanes that impart both radial and rotational motion to the fluid, increasing its velocity and kinetic energy.
- **Volute**: This spiral-shaped casing collects the high-velocity fluid discharged by the impeller. It gradually expands to reduce the velocity, converting kinetic energy into pressure (static head).
- **Diffuser**: A diffuser further improves pump efficiency by allowing a smoother and more gradual expansion of the fluid, reducing turbulence as it slows down and pressure builds.
- **Packing**: Installed around the pump shaft where it passes through the casing, packing materials provide a seal to prevent leakage.
- **Wearing Rings**: These replaceable rings are attached to the impeller and/or pump casing. They allow a tight running clearance between the impeller and casing, minimizing wear on critical components and maintaining efficiency.

How It Works:

A **centrifugal pump** is a mechanical device used to move fluids by converting rotational energy—typically from an electric motor or engine—into fluid movement. The fluid enters the impeller axially and is flung outward through the vane tips by centrifugal force. This action increases the fluid's velocity and pressure, enabling efficient flow through the system.

1.3.1 Dynamic Pumps

Centrifugal Pumps: These are widely used types with a rotor that increases the kinetic energy of the fluid, which is then converted to pressure energy using centrifugal force. Used for applications needing high flow rates.

a) Positive Displacement Pumps

- Piston Pumps: Utilize variations in volume caused by a piston moving in a cylinder. Commonly used for precise flow rates.

- Other Types: Includes peristaltic, gear, lobe, and screw pumps, each functioning based on rotational speed.

b) Pump Failures

Improper operation of pumping stations can lead to abnormal functioning and subsequent deterioration of pump components like impellers, bearings, and bushings. This deterioration causes:

- Availability Issues: Timely replacement part procurement.
- Labor Costs: Increased maintenance labor.
- Production Losses: Downtime affecting the production cycle.

c) Methodology for Vibration Analysis and Diagnosis

Combining numerical simulations with experimental data proves effective in systematically addressing and diagnosing faults in rotating machines, especially pumps. The Finisher Pump is a centrifugal pump, this pump experienced significant mechanical failure signalled by unusual noises and strong vibrations. This malfunction led to a progressive misalignment of the shaft, wear of bearing seals, and bearing defects, prompting the shutdown of the machine to prevent more severe damages.

The steps involve:

- Numerical Simulations: Predict expected vibration characteristics.
- Experimental Measurements: Gather real-world vibration data.
- Data Comparison: Validate simulation results with experimental findings to identify design flaws or operational issues.
- Solution Implementation: Propose and apply corrective measures to mitigate identified faults.

1.4 Description of the Finisher Pump

The Finisher Pump is a centrifugal pump, which is central to the production line

- Aspirating the product through an inlet pipe from a storage tank's bottom.
- Expelling the paste at higher pressure through an outlet pipe to the top of the tank.
- Utilizing steam to dry the product.

The pump operates via a rotating impeller that imparts kinetic energy to the fluid, which is then converted into pressure energy due to the pump's body geometry.

The mechanical seal's primary role in the finisher pump is to:

- Contain the pumped fluid inside the pump while enabling the rotation of the shaft, which is vital for the pump's proper function and safety.

The Finisher Pump is a vital component in the production line with specific technical parameters and features that ensure its efficient operation. Awareness and maintenance of its components, such as the electric motor, bearings, seals, and coupling, are crucial for longevity and optimal performance.

1.5 Conclusion:

This comprehensive approach to understanding and maintaining rotating machines through vibration analysis and predictive maintenance strategies enhances machine reliability and longevity. Implementing advanced monitoring technologies and maintaining a robust maintenance protocol addresses faults before they escalate into major failures, ensuring continuous and efficient industrial operations.

1.6 Summary of Learning Objectives:

- Understanding Complex Behaviors: Gain insights into the complex operations of rotating machinery.
- Experimental Studies: Conduct on-site experimental analyses to monitor machine health.
- Fault Diagnosis: Identify mechanical faults through precise diagnostic tools.
- Performance Optimization: Enhance machine performance through optimized maintenance strategies.
- Modal Analysis: Theoretically establish modal analyses to predict machine behavior and failures.
- Reliability Improvement: Use simulations to improve machine reliability and durability.

By following these methodologies and understanding the critical aspects outlined, industrial operators can ensure efficient, reliable, and cost-effective operation of their rotating machinery assets.

Chapter II:

Vibratory Diagnostics in Centrifugal Pump Systems: A Technical Analysis

2 Vibratory Diagnostics in Centrifugal Pump Systems: A Technical Analysis

2.1 Introduction:

Vibratory diagnostics is a pivotal field within mechanical engineering, focusing on ensuring the stability and longevity of rotating machinery. This analysis delves into the technical characteristics and operational challenges of a centrifugal pump system, specifically applied within a food processing facility.

2.2 Technical Characteristics of the Centrifugal Pump System

The centrifugal pump system under study is a crucial component in a tomato canning production line. Its primary role is to function as a finisher, which is integral to the continuity and efficiency of the production process.

- Role of the Pump: The centrifugal pump is responsible for the final processing phase in the product line.
- Impact of Pump Failure: A significant mechanical failure was reported, characterized by unusual noise and strong vibrations. This condition indicated serious underlying issues that necessitated a thorough diagnostic analysis [4].

a) Mechanical Faults and Diagnostic Findings

- Misalignment of the Shaft: Progressive misalignment of the pump's shaft was identified, which can severely affect the operational efficiency and cause premature wear of machine components.
- Bearing Defects: The unusual noises and vibrations were tied to bearing defects, which are critical for maintaining smooth operation.
- Imbalance: An imbalance in the rotating parts of the pump can lead to operational disruptions and is a common source of mechanical failure in such systems.

b) Diagnostic Approach

An in-depth vibratory analysis was conducted to pinpoint the exact faults and recommend corrective measures. The diagnostics involved the following steps:

- Vibration Monitoring: Continuous monitoring of vibration levels to detect anomalies early.
- Noise Analysis: Identifying and analyzing abnormal noises to trace back to potential mechanical faults.

- Maintenance and Repair: Based on diagnostic findings, the necessary maintenance and repair procedures were outlined to restore the pump's operational integrity.

Effective vibratory diagnostics are essential for the maintenance of centrifugal pump systems, ensuring their reliable and efficient operation. By addressing mechanical faults such as misalignment, bearing defects, and imbalance early, significant operational disruptions can be avoided, thereby extending the service life of the machinery and ensuring the smooth operation of the production process.

- Vibratory diagnostics is crucial in maintaining the health of rotating machinery.
- A centrifugal pump in a tomato canning line experienced significant mechanical failure due to misalignment, bearing defects, and imbalance.
- Early detection through vibration and noise analysis is vital to prevent severe operational disruptions.
- Regular maintenance and prompt corrective measures can ensure the longevity and reliability of the pump system.

Figure 2-1 : centrifugal pump assembly

2.3 Machine description:

Comprehensive Guide to the Operation and Maintenance of the Centrifugal Pump in Tomato Paste Production

Centrifugal pumps are critical components in various industrial processes, including the tomato paste production industry. This guide will delve into the operational principles, maintenance routines, and troubleshooting procedures essential for the effective use of centrifugal pumps, specifically in the context of tomato paste processing.

2.3.1 Description of the Centrifugal Pump

- Functionality: Essential in the production chain for fluid transfer.

- Primary Role: To aspirate product through an inlet pipe from the base of a storage tank and discharge it at a higher pressure through an outlet pipe.

- Mechanism: Relies on the rotation of an impeller, which imparts kinetic energy to the fluid. This energy is then converted into pressure energy by the pump casing's geometry.

2.3.2 Key Components

- Impeller: The rotating part that imparts kinetic energy to the fluid.
- Pump Casing: Converts kinetic energy into pressure energy, enabling fluid movement.
- Inlet and Outlet Pipes: Facilitate the fluid's entry and exit, ensuring efficient transfer and pressure management.
- Steam Integration: Helps in drying the paste and increasing its concentration.

2.3.3 Maintenance Routines

- Visual inspection for leaks or unusual noises.
- Ensure that the inlet and outlet pipes are free of obstructions.

➢ Weekly Checks: Verify the alignment of the pump and motor and lubricate bearings as required.

➢ Monthly Checks: Inspect the impeller for wear and damage and check the pump casing for signs of corrosion or wear.

a) Preventive Maintenance

- Conduct through inspections during planned shutdowns.
- Replace worn-out parts, such as seals and bearings, to prevent unexpected failures.

b) Cleaning Procedures:

- Regularly clean the impeller and casing to prevent buildup of materials that can affect performance.

c) Lubrication:

- Follow manufacturer recommendations for lubrication intervals and types of lubricants to extend bearing life and ensure smooth operation.

2.3.4 Excessive Vibration or Noise:

- Possible Causes: Misalignment of the pump and motor, bearing failure, or impeller imbalance.
- Solutions:
  - Re-align the pump and motor.
  - Replace damaged bearings.
  - Balance or replace the impeller.

Understanding the operational principles, maintaining regular inspection schedules, and promptly addressing common issues are essential for ensuring the efficient and prolonged operation of centrifugal pumps in tomato paste production. Regular maintenance and proactive troubleshooting can prevent costly downtimes and enhance the overall productivity of the production line.

2.4 Components and Specifications

The Pump Finisher Module 03

- Role: Essential in food processing, specifically in product decompression.
- Location: Preparation zone.
- Motor Specifications:
  - Power: 75 kW
  - Speed: 1485 rpm
  - Frequency: 24.75 Hz
  - Manufacturer: Siemens
- Turbine Specifications:
  - Five blades
  - Outer Diameter: 420 mm
  - Hub Bore Diameter: 65 mm
  - Width: 250 mm
  - Weight: 60 kg

2.4.1 Points of Measurement

To validate vibratory conditions, strategic locations on the machine are identified, ensuring comprehensive monitoring:

- Bearings (horizontal and vertical)

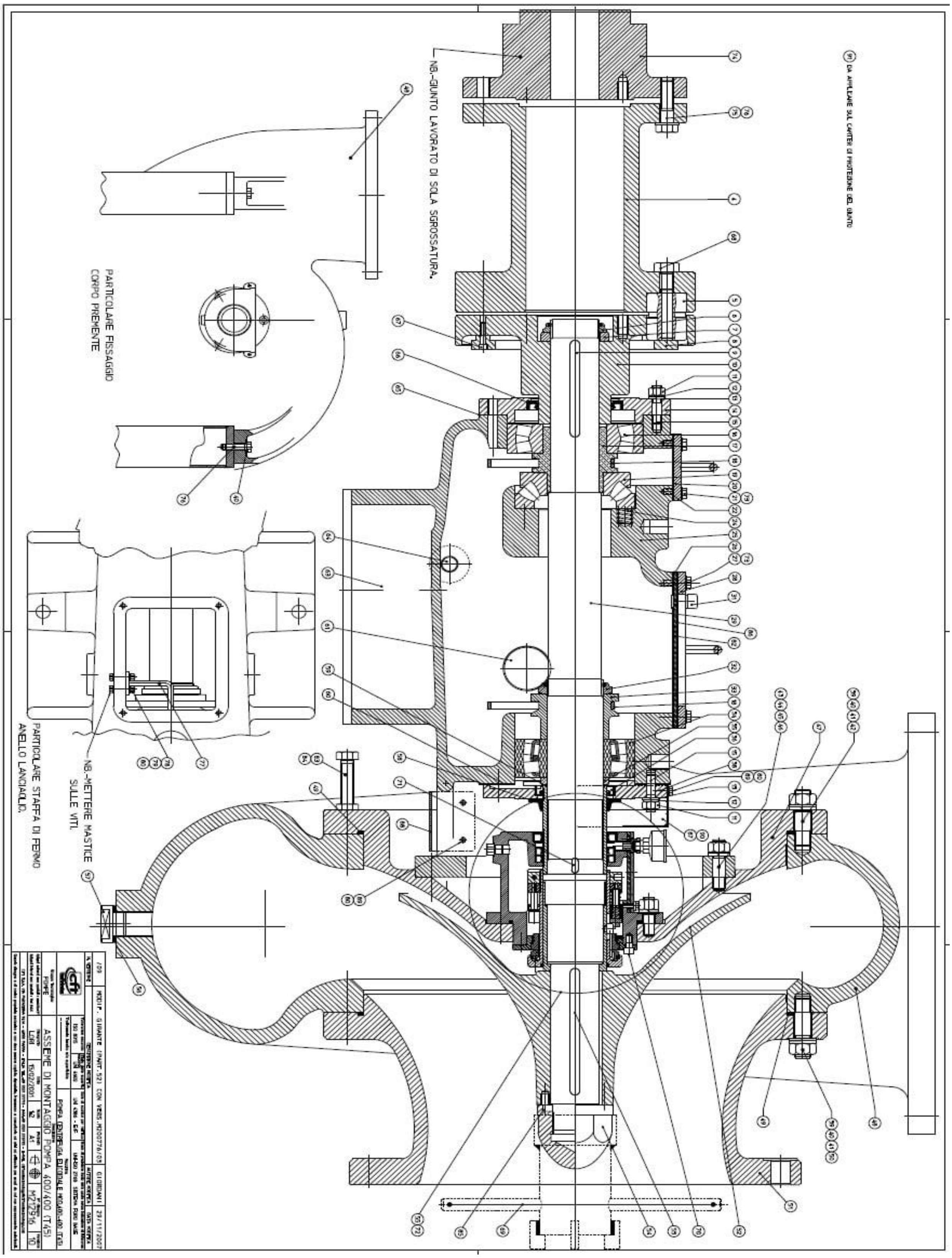

Figure 2-2 : Assembly Drawing and Cross-section of a Horizontal Centrifugal Pump

Figure 2-3: Electric Induction Motor for Industrial Pump Drive

Bearings:

2x SKF (21316 E) self-aligning roller bearings with relubrication system

Dimensions: d=80mm, D=150mm, d: inner diameter, D: outer diameter, Weight = 4526.70 g, Limit speed = 5300 r/min

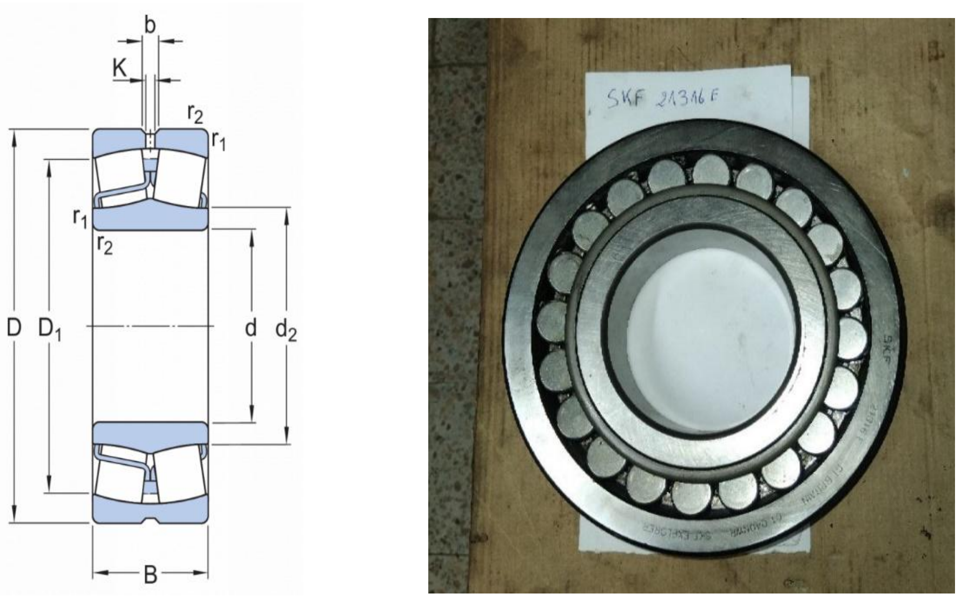

Figure 2-4: Schematic and Real View of a Self-Aligning Ball Bearing

SKF (29414 E) spherical plain bearing with stamped steel cage

Dimensions: d = 70 mm, D = 150 mm, d = inner diameter, D = outer diameter

Weight = 3810 g, Maximum speed = 4300 r/min

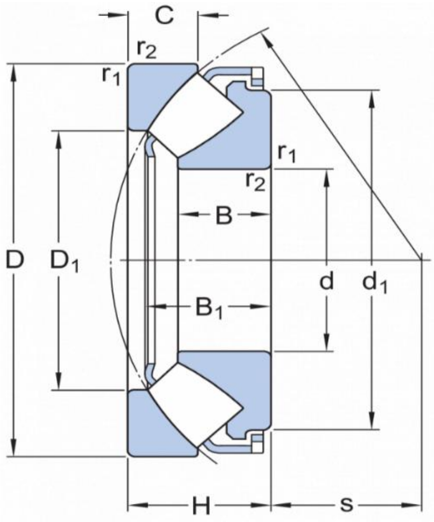

Figure 2-5: Schematic and Real View of a Self-Aligning Ball Bearing

The necessary (seal): The main role of the mechanical seal in this finisher is to contain the pump fluid inside the pump while allowing the shaft to rotate.

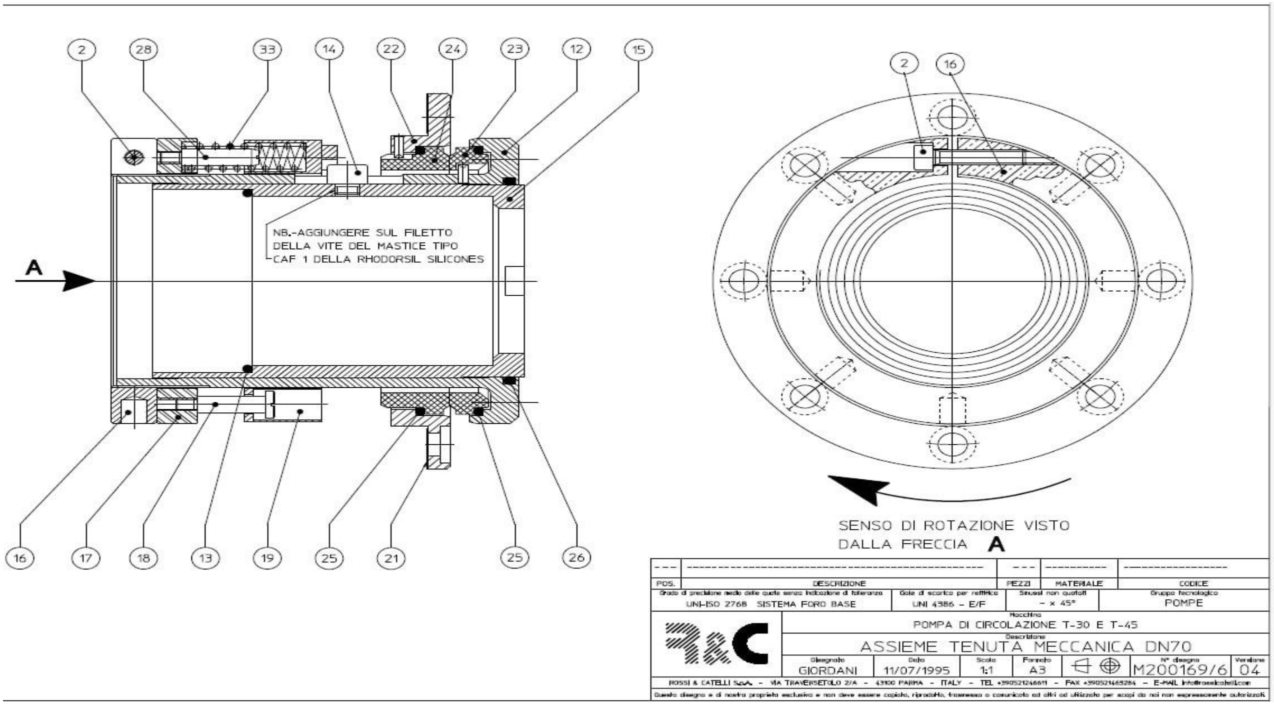

Figure 2-6: Technical Assembly Drawing of a Motor Shaft seal with Sectional and Top Views

Reference	Reference code	Part Description
2	VGD030	Screw
12	M200141	Bushing
13	GUG052	O-Ring
14	M200133-02	Screw
15	M200140	Bushing
16	M200138	Clamp
17	M200137	Spring Ring
18	M200132	Screw
19	M200136	Pressure Ring
21	M200698	Gasket
22	M200142	Flange
23	M200135	Rotating Seal
24	M200134	Stationary Seal
25	GUH064	O-Ring
26	GUH056	O-Ring
28	M200131	Screws
33	BO50016/07	Springs

Table 2-1 table of names of drawing parts for necessary

Figure 2-7: Real View of The necessary

Coupling:

- Two hubs: The red, ring-shaped parts that attach to each shaft.

- A center member: The thicker red part between the two hubs.

- Bolts: The fasteners that hold the hubs and center member together.

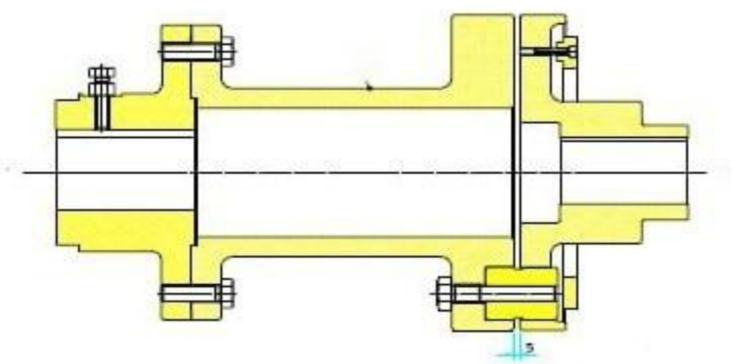

Figure 2-8: Schematic and Real View of Coupling

Type de lubrificant	Lubricant type Brand Oil	capacity in liters
Huile	AGIP OTE 68	8

Table 2-2:Rolling Body Characteristics

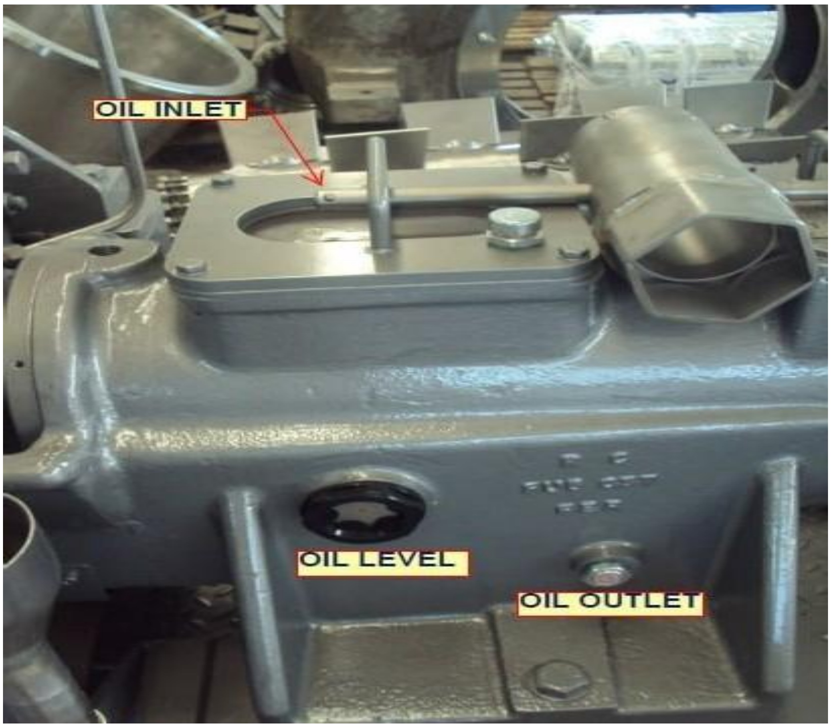

Figure 2-9: Real View of Body Rolling

The turbine:

An impeller consists of three spiral blades, helically formed to generate a centrifugal flow.

Material: Stainless steel.

Geometry: Three curved blades attached to a central hub, designed to fit onto the drive shaft.

2.5 Analysis of Vibratory Diagnostics in Centrifugal Pump Systems

2.5.1 Importance of Vibratory Diagnostics

Vibratory diagnostics is essential for multiple reasons:

- Predictive Maintenance: Detects early signs of failure allowing for timely interventions.

- Operational Efficiency: Ensures machinery operates at optimal performance.

- Cost Management: Prevents expensive downtime and repairs by addressing issues early.

2.5.2 Mechanical Faults and Their Implications

a) Misalignment

- Parallel Misalignment: Shaft center lines are parallel but offset.

- Angular Misalignment: Shafts angle towards each other.

- Detection: Anomalies in vibratory signatures can indicate misalignment.

- Consequences: Increased load and potential damage to components like bearings and seals.

b) Bearing Defects

- Surface Defects: Pits, cracks, and spalls on bearing surfaces.

- Lubrication Failures: Inadequate lubrication leading to increased friction and wear.

- Detection: High-frequency vibration and noise are characteristic indicators.

- Consequences: Reduced lifespan and efficiency, potential for catastrophic failure.

c) Imbalance

- Static Imbalance: Uneven distribution of mass in a stationary rotor.

-Dynamic Imbalance: Uneven mass distribution during rotation.

- Detection: Uneven vibratory patterns, especially at specific rotational speeds.

- Consequences: Magnified stress on bearings and support structures leading to premature wear.

d) Diagnostic Techniques

Exploiting vibratory patterns enables precise identification of faults. Common techniques include:

- Waveform Analysis: This considers time-domain data to identify transient events like impacts or rapid changes in vibration.

- Spectral Analysis: Uses frequency-domain data to locate characteristic frequencies associated with different faults.

- Envelope Analysis: Ideal for detecting bearing defects by demodulating high-frequency carrier signals.

2.6 Case Study: Centrifugal Pump in a Food Processing Facility

Figure 2-1: centrifugal pump assembly

a) Initial Symptoms

- Vibration Analysis: Unusual vibrations detected during routine monitoring.

- Audible Noise: Indicative of bearing or alignment issues.

b) Diagnostic Process

- Initial Inspection: Visual and manual checks for alignment and wear.
- Data Collection: Sensors placed to collect time and frequency domain data.
- Analysis: Spectral and envelope analysis revealed misalignment and bearing defects.
- Intervention: Realignment and bearing replacement strategies were implemented.

c) Results

- Post-Intervention Monitoring: Significant reduction in vibration and noise levels.

- Operational Improvements: Enhanced reliability and efficiency of the centrifugal pump.

d) Recommendations for Practitioners

- Regular Monitoring
- Routine Checks: Implement a schedule for periodic vibratory diagnostics.
- Sensor Placement: Ensure sensors are accurately positioned for reliable data collection.

e) Training and Awareness

- Operator Training: Equip personnel with knowledge and skills for identifying and responding to diagnostic data.
- Updated Protocols: Regularly update diagnostic and maintenance protocols based on the latest industry practices.

f) Advanced Techniques

- Automated Diagnostics: Invest in automated systems that can continuously monitor and analyze vibratory data.
- Remote Monitoring: Utilize IoT-enabled devices for real-time, remote diagnostics to minimize inspection times and operational downtimes.

2.7 Conclusion

Vibratory diagnostics provide a powerful toolset for maintaining the operational integrity of centrifugal pumps. By understanding key mechanical faults and employing advanced diagnostic techniques, facilities can significantly reduce the risk of unexpected failures, thereby enhancing both their operational efficiency and cost-effectiveness [5,6 and 7]

Chapter III:

Experimental Study of a rotating Machine: The Case of a centrifugal Finisher Pump

3 Experimental Study of a rotating Machine: The Case of a centrifugal Finisher Pump

3.1 Introduction

The study focuses on the vibratory analysis of rotating machines, specifically a centrifugal finisher pump. The importance of this study lies in its potential to improve predictive maintenance, reduce downtime, and enhance overall operational efficiency in industrial settings.

3.1.1 Objectives of the Study

- To understand the vibratory behaviour of centrifugal pumps.
- To identify the key factors contributing to vibratory issues.
- To develop strategies for mitigating undesirable vibrations.

3.1.2 Experimental Setup

- Description of the centrifugal finisher pump used.
- Setup of vibration sensors at key locations on the pump.

a) Instruments and Materials Used

- List of sensors, data acquisition systems, and software for analysis.

b) Data Collection Procedures

- Step-by-step process of data collection during various operating conditions.
- Ensuring accuracy and reliability of data.

c) Vibratory Analysis

- Importance of vibratory analysis in maintaining rotating machinery.
- Different types of vibratory tests conducted.

d) Analysis Techniques

- Modal Analysis: To determine the natural frequencies and mode shapes.

e) Expected Outcomes

- Identification of critical frequencies causing excessive vibrations.
- Development of vibration mitigation strategies.

f) Results and Discussion

- Graphical representation of vibratory data collected.
- Key findings in terms of amplitude, frequency, and phase information.

h) Interpretation of Results

- Understanding the correlation between operational parameters and vibratory behavior.
- Identifying root causes of abnormal vibrations.

i) Comparison with Theoretical Predictions

- How experimental results align or differ from theoretical predictions.
- Possible explanations for any discrepancies observed.

j) Recommendations

- Practical recommendations for industry practitioners.
- Suggested maintenance practices to minimize vibratory issues.

This content is structured to provide a thorough comprehension of the experimental study on the vibratory analysis of rotating machines, specifically focusing on a centrifugal finisher pump.

3.2 Application : Centrifugal finisher pump

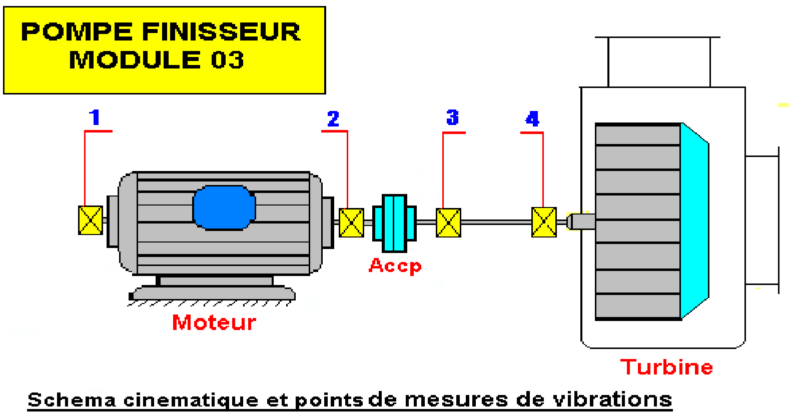

Figure 3-1 Kinematic diagram and vibration measurement points.

.

Figure 3-2 : Coupling sleeve connecting the motor shaft and the turbine shaft.

Figure 3-3: Coupling sleeve.

Figure 3-4: Shaft carrying the turbine.

Figure 3-5: Bearing reference 21316 F.

3.2.1 Machine Description:

The Module 03 Finishing Pump is a critical component in the food canning process, located within the preparation area of the plant. Its primary function is to deconcentrate the product received from other upstream condenser pumps. The system is powered by a 75-kW electric motor that drives a horizontal shaft supported by oil-lubricated bearings, which in turn actuates a turbine impeller (figure 3-1).

This type of equipment is classified as large rotating machinery per ISO 20816-1 [8] and its monitoring is essential to prevent unscheduled downtime, especially given its central role in the production line [9].

3.2.2 Selection of Vibration Measurement Points:

The vibration measurement points are chosen to accurately obtain the required information [14,15,16]. Our objective in this case is to determine the overall condition of the machine. It is therefore necessary to know the condition of the system's bearings as well as the behavior of the horizontal shaft carrying the turbine being studied. Figure 3-4 allows the machine to be studied and the vibration measurement points on the bearings to be selected, which will be used to detect any faults that may arise on the machine during its operation. The measurement points are programmed in such a way that all frequencies of interest can be captured and their changes monitored in both horizontal and vertical directions.

3.2.3 Machine History

Monitoring using the vibration analysis method of the machine began on: July 31, 2022, or spectral interpretation does not reveal any anomalies that could be cited, with the exception of a slight misalignment between the motor shaft and the turbine shaft, generating vibrations with an overall level of 04 mm/s on the motor bearing in the horizontal direction, as shown in trend curve 3-6. Table 3-1 summarizes the interventions carried out on the machine. We note that in July 2024, the recorded vibration level took an upward trend of 13.57 mm/s, considered Dangerous by referring to the vibration judgment criteria, according to the international standards VDI 2056. This evolution of the vibration level is due to the presence of a bearing defect in the two bearings No. 03 and 04.

Measurement date	Measurement date	Overall vibration level in (mm/s) on bearing No. 02, vertical direction	Overall vibration level in (mm/s) on bearing No. 03, vertical direction	Overall vibration level in (mm/s) on bearing No. 04, horizontal direction	Replacement of the turbine shaft bearings.
July 31, 2022	31 Juillet 2022	04	03,21	03,21	Replacement of the turbine shaft bearings. Replacement of the coupling.
March 26, 2024	26 Mars 2024	01,82	03,63	05,19	Draining and changing of the bearing lubricating oil.
July 8, 2024	08 Juillet 2024	05,60	10,91	06,44	Draining and changing of the bearing lubricating oil.
July 18, 2024	18 Juillet 2024	04,55	13,57	09,35	Replacement of the turbine shaft bearings.
August 13, 2024	13 Août 2024	02,87	06,14	05,40	Replacement of the turbine shaft bearings. Replacement of the coupling.

Table 3-1: Summary of vibration measurements on bearing No. 02 of the huller, as well as interventions.

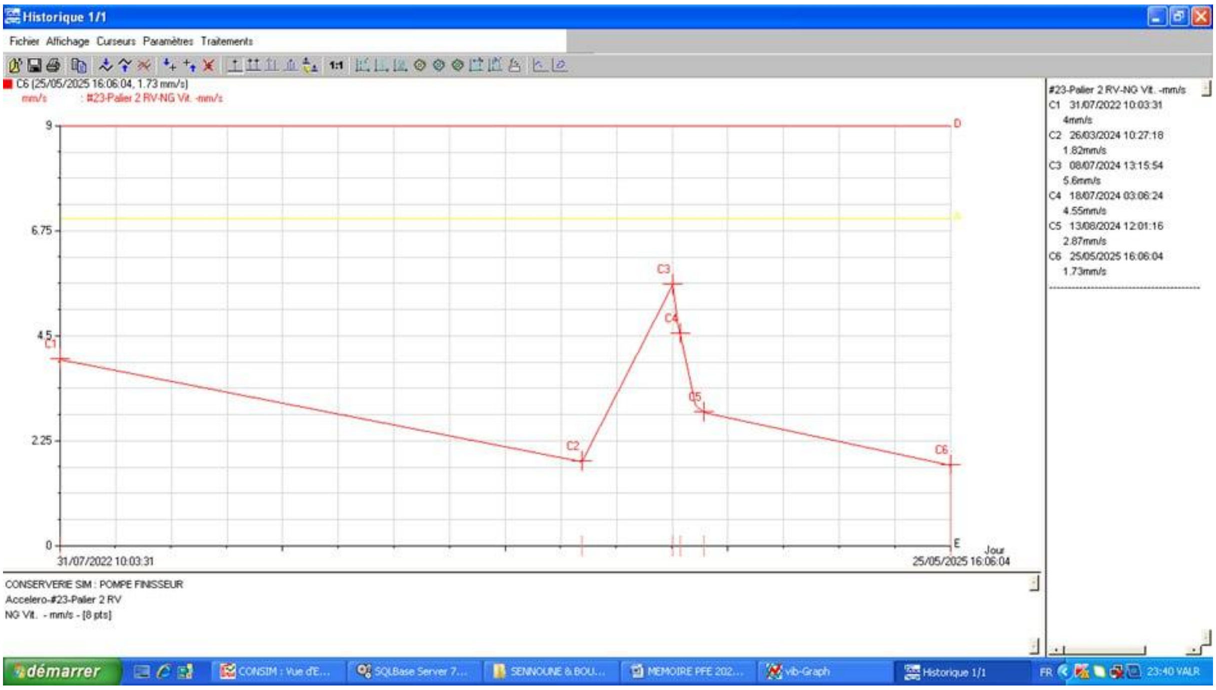

Figure 3-6: Vibration trend of the finishing pump on bearing No. 02 in the vertical direction.

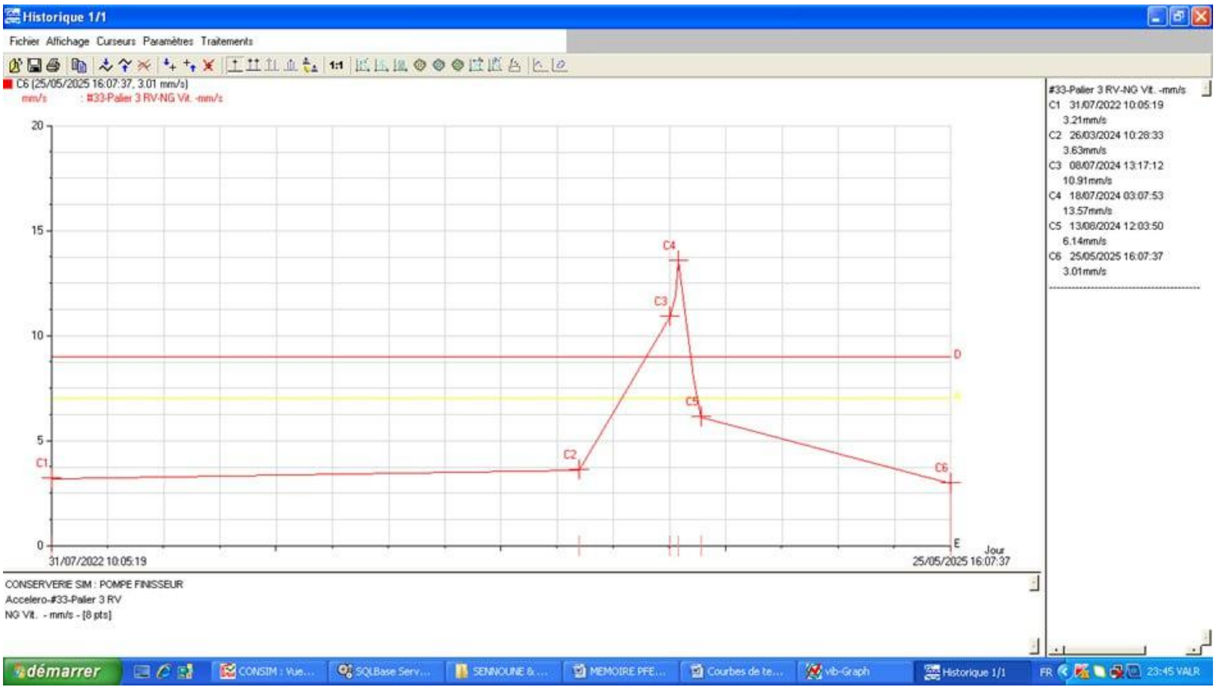

Figure 3-7: Vibration trend of the finishing pump on bearing No. 03 in the vertical direction.

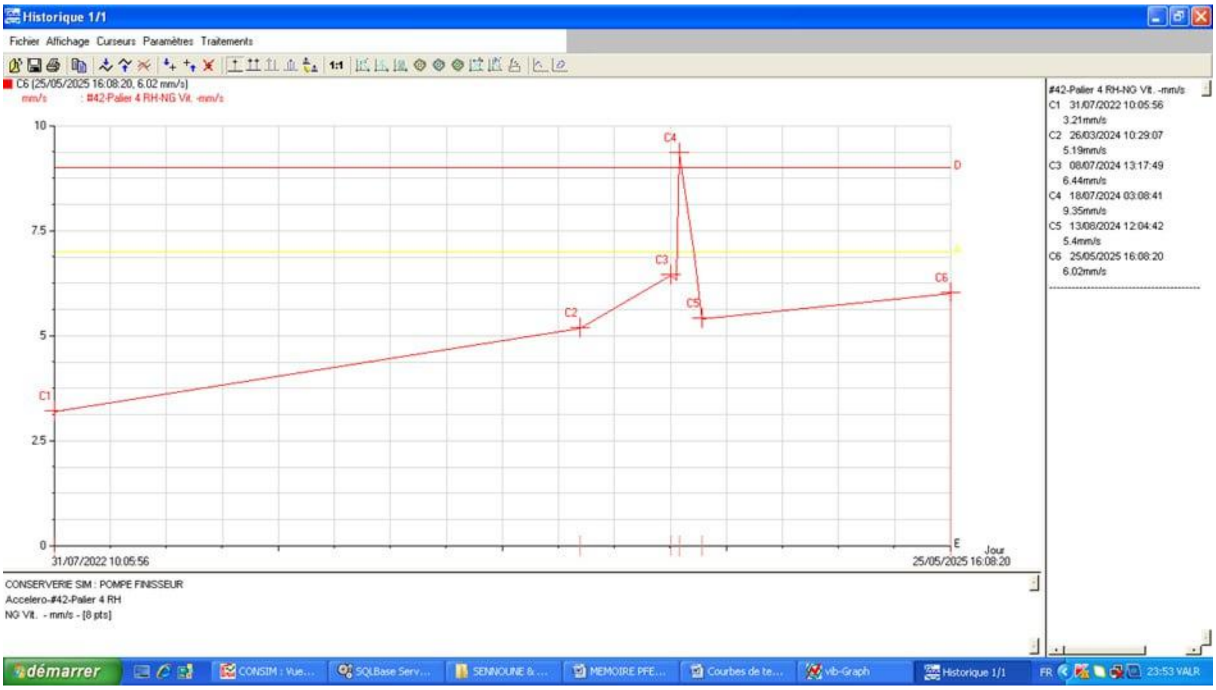

Figure 3-8: Vibration trend of the finishing pump on bearing No. 04 in the horizontal direction.

3.2.4 Vibration Diagnosis and Results Analysis [10]:

Spectral interpretation of the measurements taken across the entire machine driveline allowed us to conclude the presence of the following anomalies:

• Detection of misalignment on the coupling sleeve connecting the motor shaft and the turbine shaft, generating vibrations at a level of 0.459 mm/s at the third harmonic of the base frequency, which is 16.25 Hz, corresponding to a rotation speed of 975 rpm, deemed acceptable according to international standards VDI 2056, as indicated by the spectrum shown in Figure 4-5, taken on motor bearing No. 02, in the vertical direction, on: July 8, 2024.

• Detection of an impact on the shaft line carrying the pump rotor, this is a functional clearance between the rolling elements and the two inner and outer rings of the two bearings in the two bearings No. 03. and 04, as indicated by the two vibration spectra shown in Figures 3-7 and 3-8 respectively.

Figure 3-8 provides a window showing the vibration measurement points of the pump-finisher machine in terms of speed and vibration acceleration.

3.2.5 Work performed: (Table 3-1)

- Replacement of the bearings reference 21236 F in the two bearings Nos. 03 and 04 (several times).
- Checking the alignment between the two motor shafts and the turbine shaft.
- Checking the turbine balance.
- Changing the bearing lubricating oil.

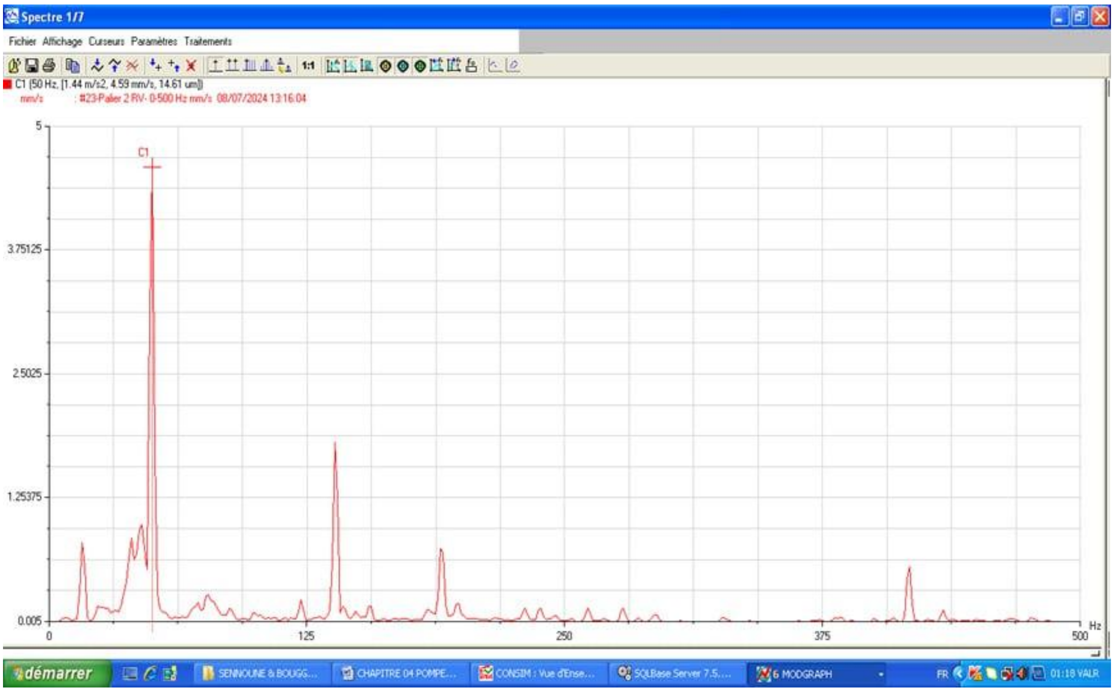

Figure 3-9: Spectrum taken on motor bearing No. 02 in the vertical direction

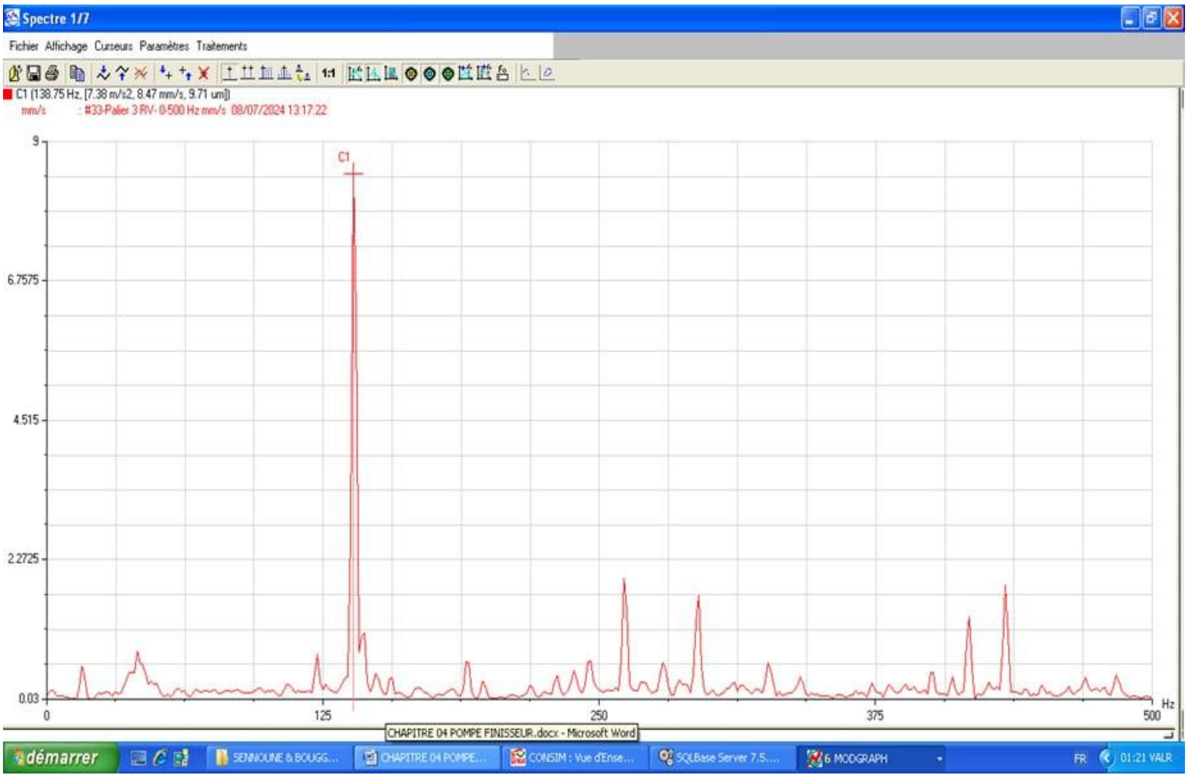

Figure 3-10: Spectrum taken on motor bearing No. 03 in the vertical direction

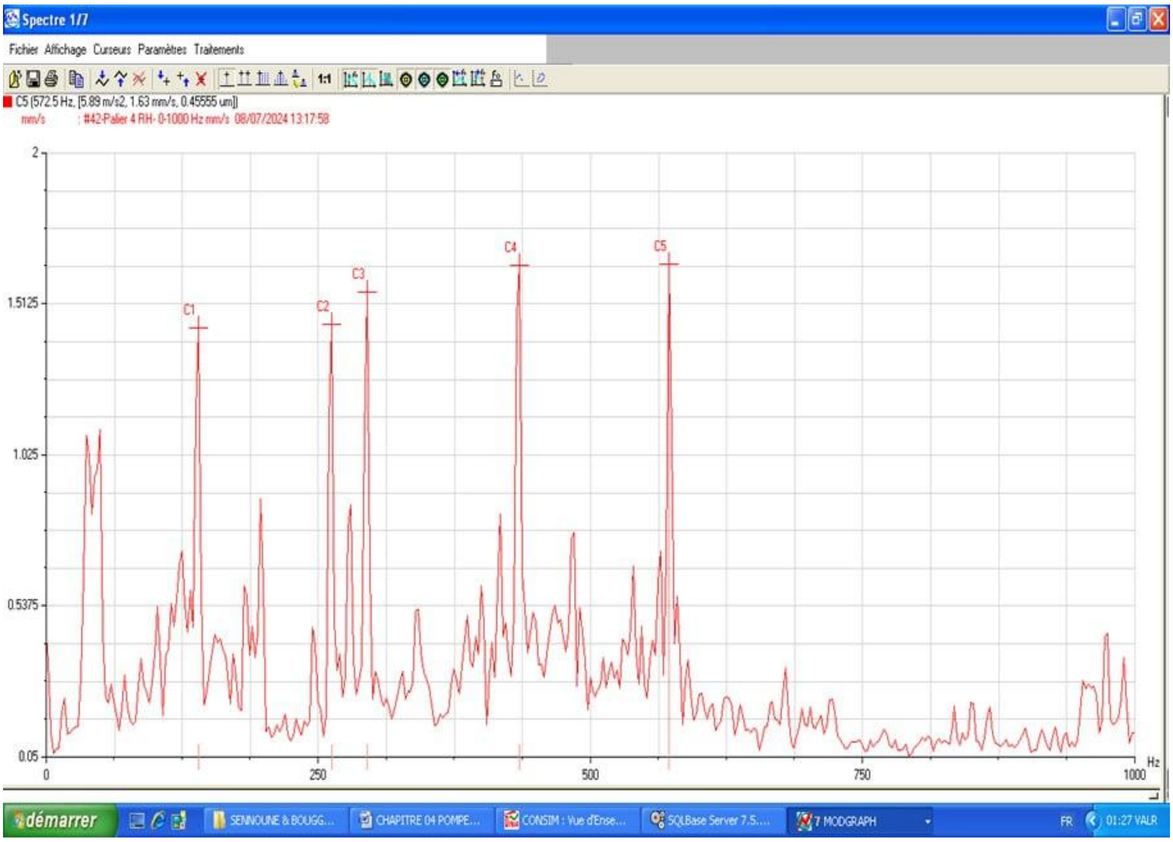

Figure 3-11: Spectrum taken on motor bearing No. 03 in the vertical direction

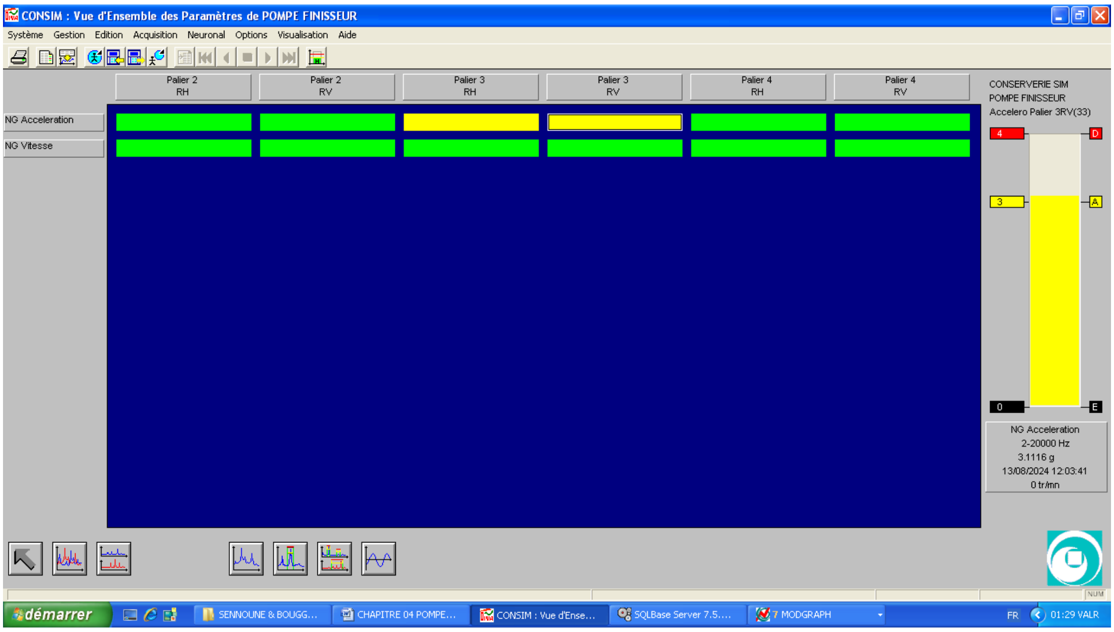

Figure 3-12: Presentation of the vibration monitoring window across the entire kinematic chain of the Pump Finisher machine.

frequency	Date	Commentry
50 Hz.	July 8, 2024	Reveals the presence of a misalignment of: 04.59 mm/s
138.75 Hz.	July 8, 2024	Reveals the presence of a bearing defect. Cage peak: Level of 08.47 mm/s
572.5 Hz	July 8, 2024	. Reveals the presence of a bearing defect. Cage peak: Level of 01.63 mm/s

Table 3-2: interpretation of results.

3.3 Conclusion

In the realm of mechanical engineering, particularly in the maintenance of machines, vibration monitoring plays a crucial role in ensuring their optimal performance and longevity.

Vibration Monitoring is essential for improving machine availability. It facilitates scheduling of repair and balancing interventions and ii detects multiple mechanical defects in the system.

Machines of the type being treated require vibration monitoring. This increases their availability. We were able to schedule repair and balancing interventions. The installation had several mechanical defects, including an imbalance fault related to the misalignment of the two motor shafts and the turbine shaft, as well as a bearing fault in the two bearings of the turbine shaft. These bearings were replaced several times, which forced us to review the sizing of the bearings that were the subject of our study.

In the subjected installation various mechanical defects were detected, primarily focusing on:

- Misalignment of the motor shafts.
- Bearing faults within the turbine shaft.
- Multiple replacements of bearings indicated the need for a review and resizing of the bearings to fit the system's requirements better.

These recorded practical results will be compared with those obtained numerically.

Chapter IV:

Numerical Simulation and Modal Analysis of the System

4 Numerical Simulation Using SolidWorks

4.1 Introduction:

Any structure tends to vibrate at certain frequencies, known as natural frequencies or resonance frequencies. Each natural frequency corresponds to a deformation pattern called a mode shape [11]. Frequency analysis allows the calculation of these natural frequencies and their associated mode shapes. In theory, everybody possesses an infinite number of natural modes. In finite element analysis (FEA), the model has as many modes as it has degrees of freedom. However, in most practical cases, only a limited number of modes are considered. Resonance is the excessive response that occurs when a structure is subjected to dynamic loading that matches one of its natural frequencies. For example, a vehicle may experience strong vibrations at a certain speed due to the resonance of an unbalanced wheel. These vibrations decrease or disappear at other speeds. Frequency analysis helps avoid resonance by identifying critical natural frequencies. It also provides valuable insights for resolving issues related to dynamic response. The system on which we will perform the frequency analysis consists of the shaft line supporting the pump finisher turbine.

Any mechanical structure, regardless of its complexity, tends to vibrate when subjected to dynamic loads. These vibrations occur at specific frequencies known as **natural frequencies** or **resonance frequencies**. At each of these frequencies, the structure exhibits a unique deformation pattern, referred to as a **mode shape**. Identifying these frequencies and mode shapes is critical in predicting and avoiding structural resonance, which can lead to failure or reduced performance.

In this section, a numerical simulation of the mechanical system was carried out using **SolidWorks Simulation**, a powerful finite element analysis (FEA) tool integrated into the SolidWorks CAD software. The main objective of this simulation is to evaluate the mechanical behaviour of the system under different loading conditions, validate the design, and identify potential areas of weakness or failure [11], [12].

Modal analysis is a type of frequency domain analysis that allows engineers to determine the natural frequencies and corresponding mode shapes of a structure. This is especially important when the system is exposed to time-varying or oscillatory forces. If the frequency of an external force coincides with one of the natural frequencies, **resonance** may occur, resulting in excessive amplitudes, fatigue damage, or even structural failure.

By performing modal analysis, we can:

- Predict the dynamic behavior of the structure.
- Identify critical frequencies that must be avoided during operation.
- Guide design modifications to shift resonance frequencies away from operating ranges.
- Validate or improve the structural integrity of the system under vibratory conditions.

4.2 Theory and Finite Element Application

In theory, every physical object has an infinite number of natural modes. In practice, however, we rely on **finite element analysis (FEA)** to approximate the structure's behavior [13] The number of computed modes is directly related to the **degrees of freedom (DOF)** in the finite element model. For large and complex systems, calculating only the first few (typically 5–20) modes is often sufficient, since they are the most likely to be excited under typical operating conditions.

FEA software such as **SolidWorks Simulation** provides numerical tools to perform modal analysis. The simulation involves solving the eigenvalue problem derived from the equation of motion:

$$[M]\{\ddot{u}\} + [K]\{u\} = 0 \qquad (4.1)$$

Where:

- $[M]$ is the mass matrix
- $[K]$ is the stiffness matrix
- $\{u\}$ is the displacement vector
- The eigenvalues correspond to the square of the natural frequencies

4.3 Application to the Studied System

In this study, the system under consideration is the **shaft line supporting the pump finisher turbine**. This rotating shaft assembly is particularly sensitive to vibratory effects due to its length, rotational speed, and connection to other mechanical components.

The modal analysis aims to:

- Determine the first few natural frequencies of the shaft line.
- Identify the mode shapes that could pose a risk during operation.
- Assess whether any natural frequencies fall within the expected operational frequency range of the turbine.

Appropriate boundary conditions were applied to represent the actual supports and constraints of the shaft. Material properties such as density, Young's modulus, and Poisson's ratio were defined based on the actual shaft and turbine materials. A suitable mesh was generated to capture both global and localized modes accurately.

4.4 Expected Outcomes and Design Implications

From the modal analysis, we expect to obtain a set of natural frequencies (e.g., the first five modes) and their corresponding mode shapes. If any of these frequencies are close to the operating frequency of the turbine (or its harmonics), design adjustments may be necessary — such as:

- Modifying the geometry or thickness of the shaft
- Adding damping elements
- Changing support conditions
- Altering material selection

4.5 Simulation of the Rotor-Pump Finisher System Using SolidWorks

The design and numerical simulation of the system using SolidWorks allows us to determine the **natural modes and frequencies** of the system (Figure 4-1).

Through the use of **SolidWorks Simulation**, a finite element analysis (FEA) module integrated into the SolidWorks CAD environment, we conducted a modal analysis on the rotor-shaft assembly that drives the pump finisher. This simulation enabled a better understanding of the system's dynamic behavior and helped identify the critical frequencies that could lead to resonance during operation.

a) Modeling and Setup

The 3D CAD model of the rotor-pump assembly was first created in SolidWorks, ensuring realistic dimensions and precise representation of all mechanical components, including the shaft, impellers, housing, and support structures. All materials were defined according to the actual system specifications—for example, structural steel or aluminum alloys depending on the component.

The model was then imported into the Simulation module where the following steps were taken:

- **Material assignment**: Each component was assigned mechanical properties such as Young's modulus, density, and Poisson's ratio.
- **Boundary conditions**: Fixed supports and bearing constraints were applied to replicate the real-world mounting of the shaft.

- **Contact definitions**: Interactions between components (e.g., shaft-bushing or rotor-housing interfaces) were modeled using bonded or sliding contacts.
- **Meshing**: A fine mesh was applied around critical areas to improve the accuracy of stress and deformation predictions, while a coarser mesh was used in less sensitive regions to optimize computational performance.

b) Modal Analysis and Results

The modal analysis was conducted to extract the system's **natural frequencies** and their associated **mode shapes**. SolidWorks Simulation solves the eigenvalue problem to calculate these frequencies, which represent the inherent vibrational behavior of the structure without external loads [14,15,16].

From the simulation, the first natural frequencies were identified. Each was accompanied by a graphical representation of the corresponding mode shape. These mode shapes revealed how the structure deforms when vibrating at each specific frequency. Particular attention was given to frequencies that fall within or near the operational range of the pump turbine, as these could indicate **resonance risks**.

Design Implications

If any of the identified frequencies overlap with the working speed or its harmonics, they could cause harmful vibrations. In such cases, design modifications may be necessary, including:

- Changing the shaft's geometry (length, diameter)
- Adding dampers or vibration isolators
- Reinforcing structural supports
- Selecting alternative materials with different dynamic properties

By identifying and analyzing these frequencies early in the design process, the system can be optimized to operate safely and efficiently, avoiding premature wear or mechanical failure due to resonance.

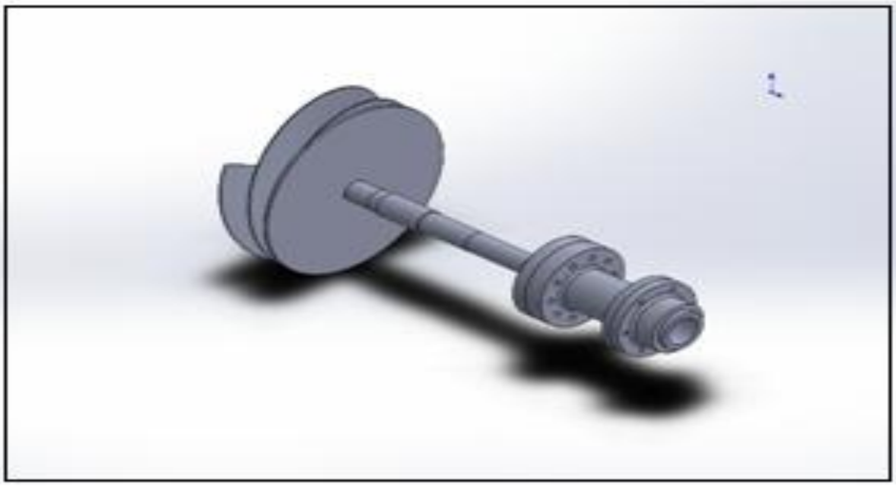

Figure 4-1: Rotor–Pump Finisher System

4.6 Simulation Study Properties

The properties of the simulation study are summarized in **Table 4-1**, while the boundary conditions and types of fixtures applied to the system are illustrated in **Figure 4-2**.

Table 4-1: Simulation Study Properties of the Fan Rotor

Study Name	Frequency
Analysis Type	Frequency
Mesh Type	Volume Mesh
Number of Frequencies	05
Solver Type	FFEPlus
Low Stiffness:	Disabled
Incompatible Bonded Contact Options	Automatic
Thermal Option	Include Thermal Loads
Zero Deformation Temperature	298 Kelvin
Include Fluid Pressure Calculated by SOLIDWORKS Flow Simulation	Disabled
Results File	SOLIDWORKS document (C:\Users\dell\Desktop\solid pump)

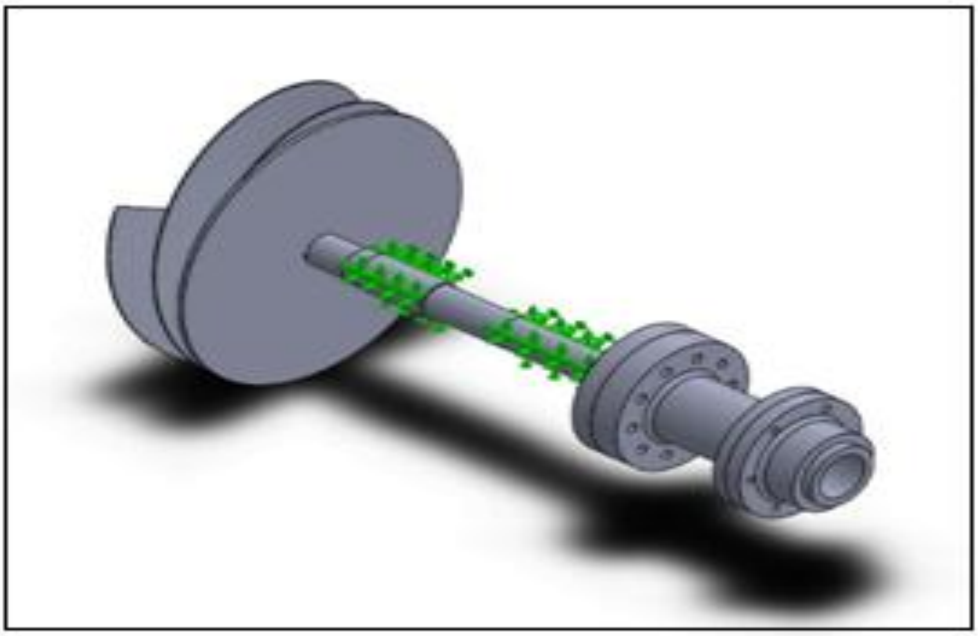

Figure 4-2: Bearing Support Fixation Conditions

4.6.1 Meshing Information

The mesh applied to the model is shown in **Figure 4-3**, and detailed meshing parameters are provided in **Table 4-2**.

Table 4-2: Meshing Information of the Model Generated in SolidWorks

Mesh Type	Volume Mesh
Mesher Used:	Standard Mesh
Automatic Transition:	Disabled
Automatic Mesh Loops:	Disabled
Jacobian Points for High-Quality Meshing	16 Points
Element Size	66.6979 mm
Tolerance	4.5922 mm
Mesh Quality	High
Remeshing Failed Parts Independently	Disabled

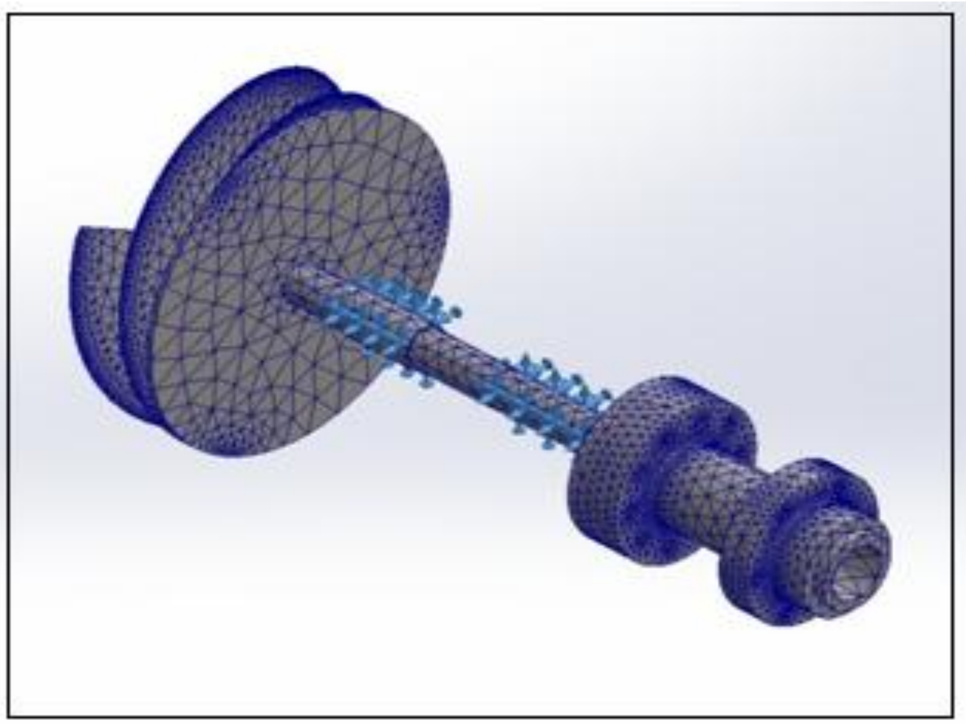

Figure 4-3: System mesh

4.6.2 Simulation Results Using SolidWorks

The modal deformations (**mode shapes**) of the system are illustrated in the following figures. These results were obtained through **modal analysis** using the SolidWorks Simulation module, which computes the system's **natural frequencies** and their corresponding **vibration modes** by solving the eigenvalue problem.

Each mode shape provides insight into how the structure deforms when it vibrates at a specific natural frequency. These deformations are typically represented as exaggerated visual displacements to make the behavior more observable and interpretable.

a) Overview of Modal Results

The first five mode shapes were analyzed, as they are generally the most relevant for dynamic response and are more likely to be excited under normal operating conditions. The results are presented in the following **Figures**, each corresponding to a specific mode.

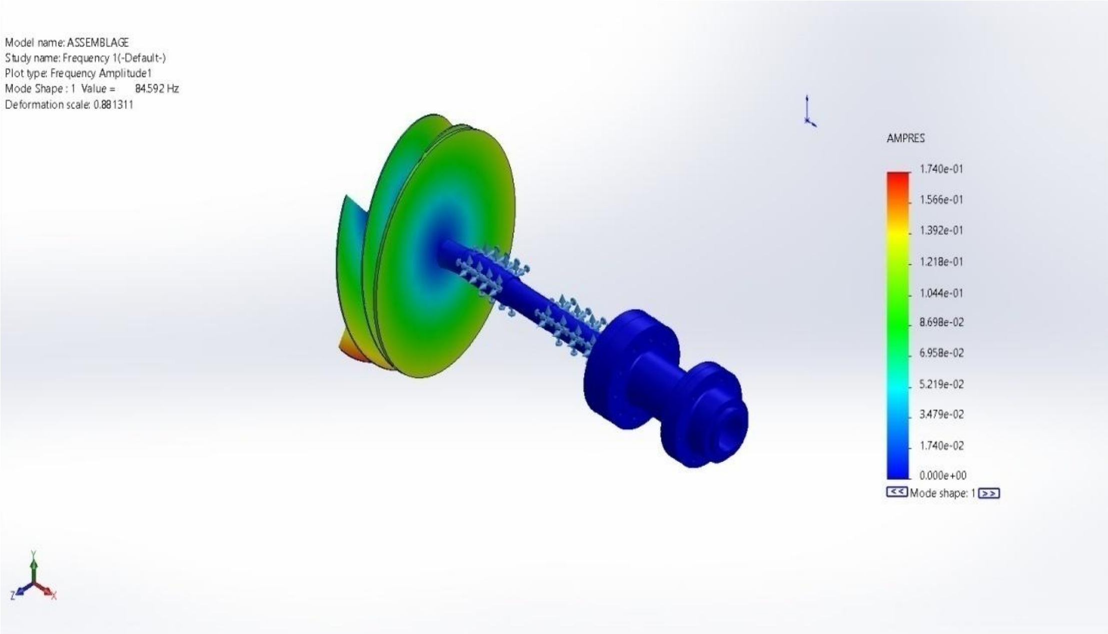

Figure 4-4: First vibration mode at a frequency of **84.5923 Hz**

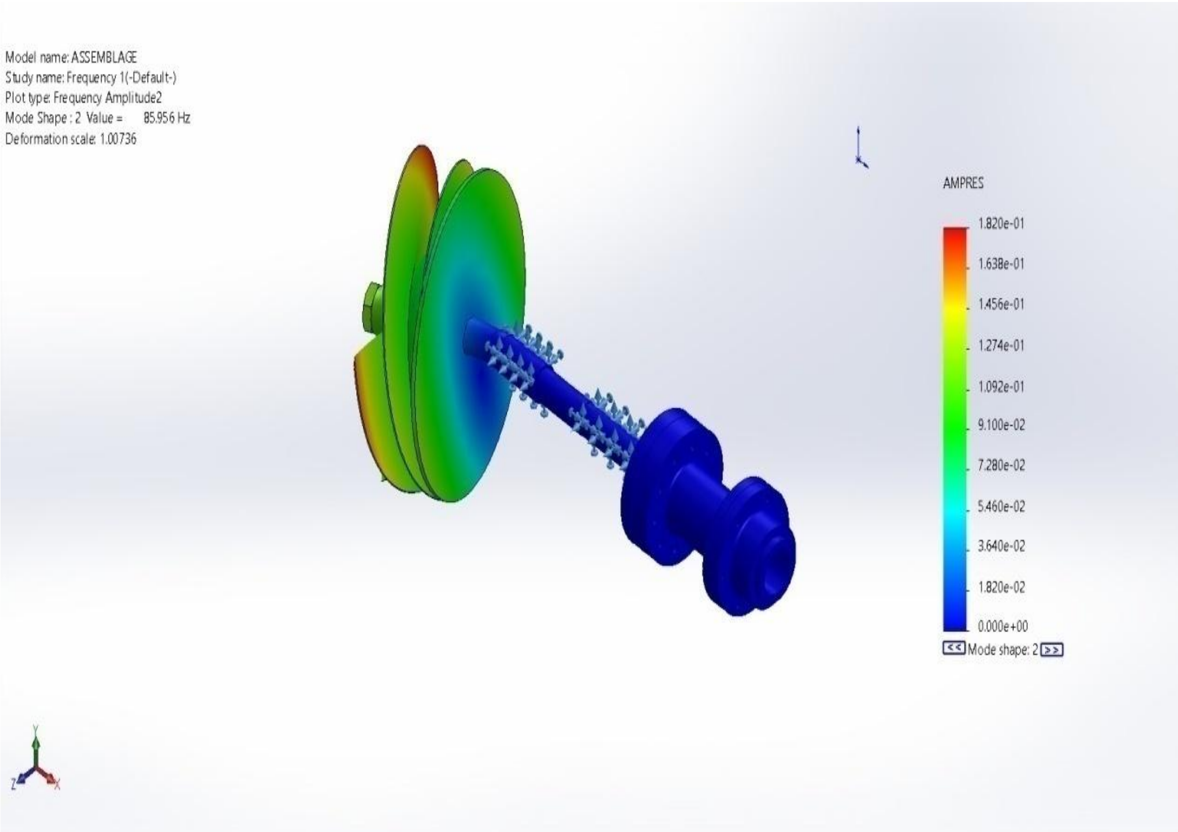

Figure 4-5: Second vibration mode at a frequency of **85.9555 Hz**

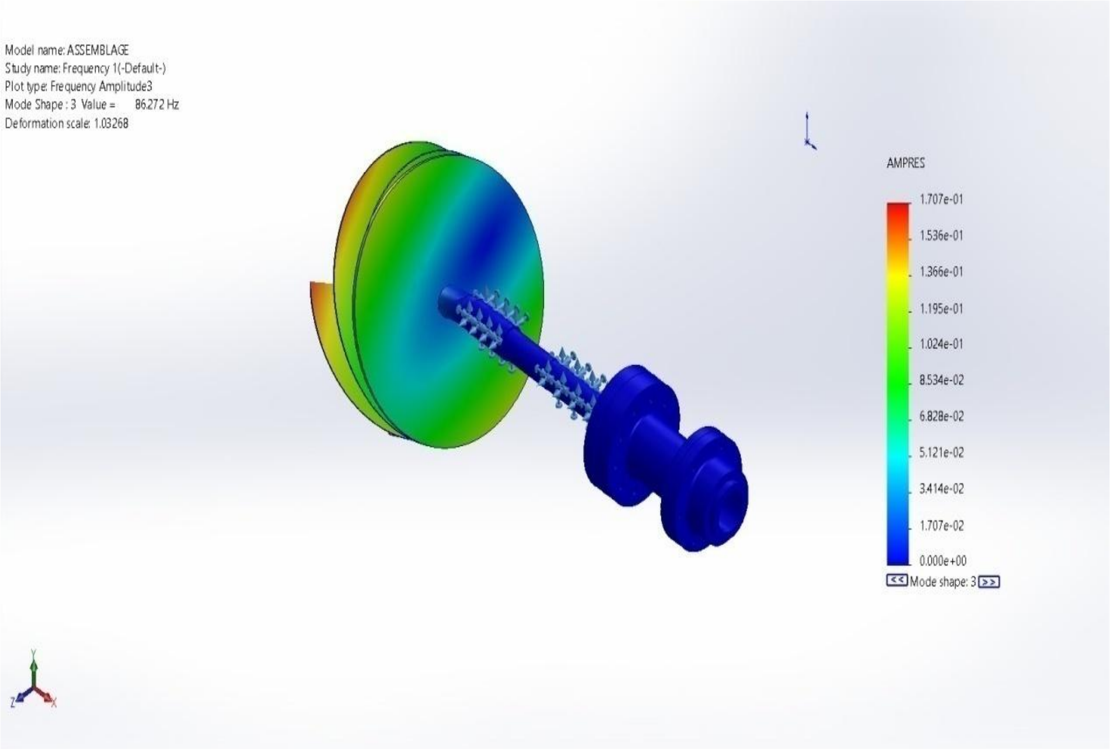

Figure 4-6: Third vibration mode at a frequency of **86.2719 Hz**

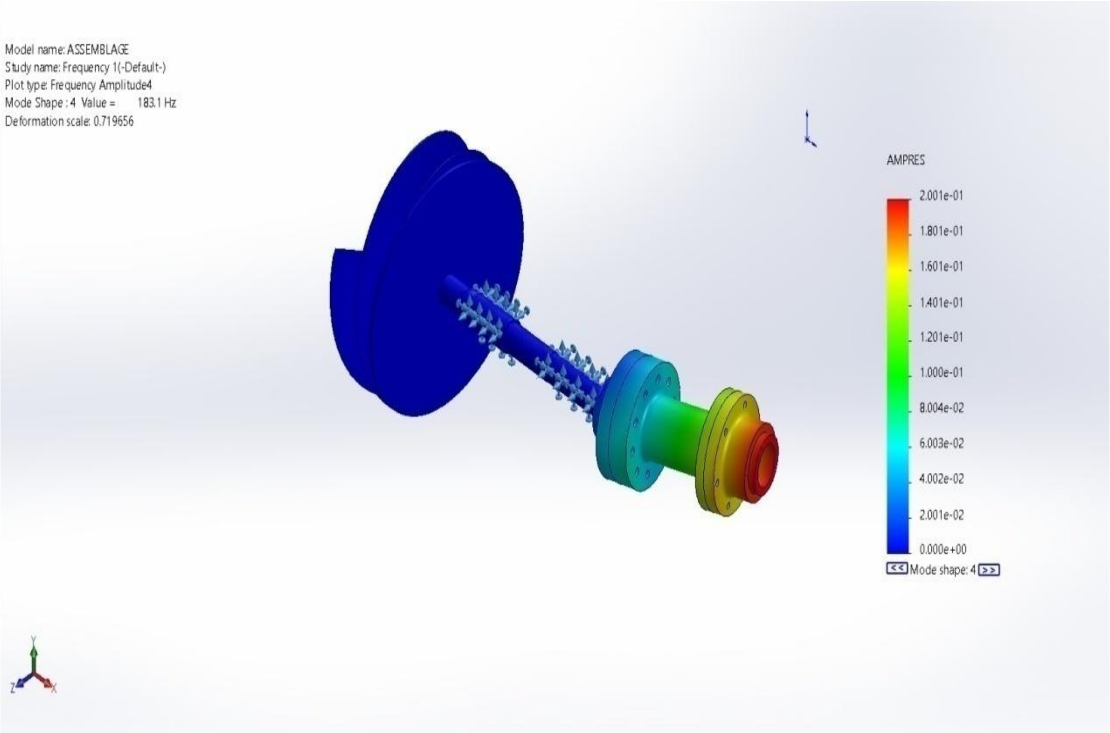

Figure 4-7: Fourth vibration mode at a frequency of **183.101 Hz**

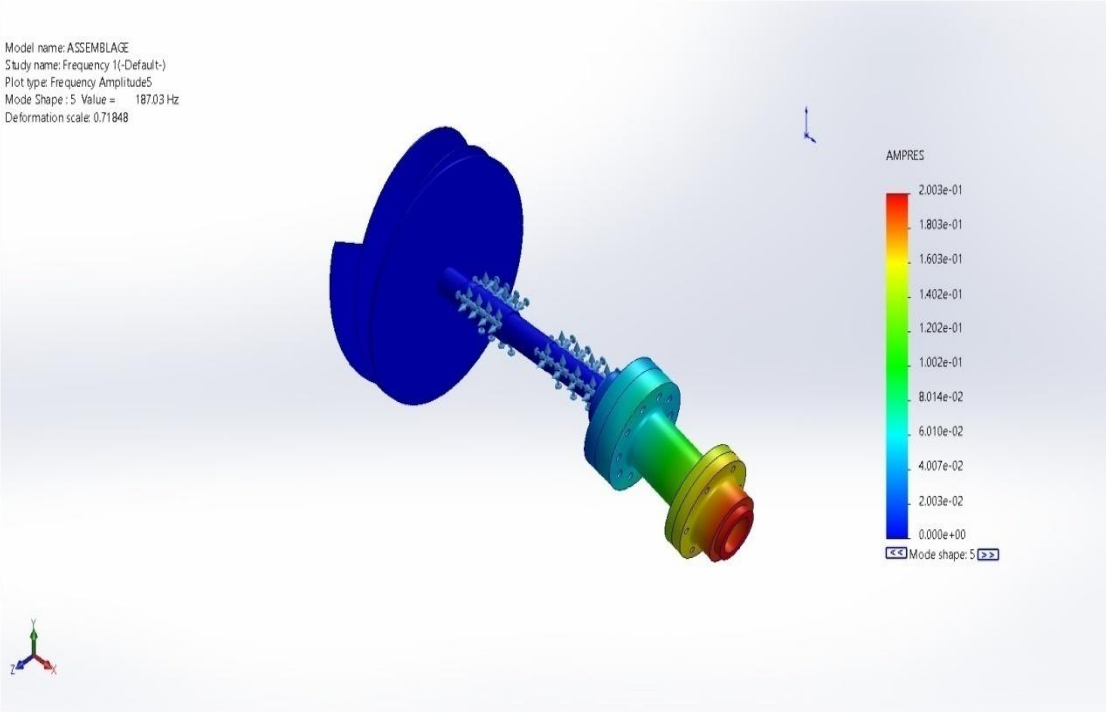

Figure 4-8: Fifth vibration mode at a frequency of **187.026 Hz**

4-1-6 List of modes:

Table 4-3: List of natural frequencies of the system established by SolidWorks

Frequency Number	Rad/sec	Hertz	Seconds
1	**531.51**	**84.592**	**0.011821**
2	**540.07**	**85.956**	**0.011634**
3	**542.06**	**86.272**	**0.011591**
4	**1,150.5**	**183.1**	**0.0054615**
5	**1,175.1**	**187.03**	**0.0053468**

4.7 Interpretation of Simulation Results

The results of the modal analysis conducted using SolidWorks Simulation are summarized in Table 4-3, and visually presented in Figures 4-4 through 4-8. This analysis provides key insights into the dynamic behavior of the rotor–pump finisher system by identifying its natural frequencies and corresponding mode shapes.

a) Symmetry and Modal Behavior

Due to the geometrical and material symmetry of the system, the first three natural frequencies are very close in value—84.592 Hz, 85.956 Hz, and 86.272 Hz—indicating a set of conjugate and symmetric vibration modes. This pattern is typical in symmetric rotating systems and reflects theoretical expectations from structural dynamics. These three modes correspond to bending modes, characterized by lateral deflections of the shaft along different planes and axes. The fourth and fifth modes, at 183.101 Hz and 187.026 Hz, respectively, represent torsional modes. These involve twisting motion along the shaft's longitudinal axis, which is critical for systems transmitting torque, such as this rotor-driven pump assembly.

b) Dominance of Bending Modes

Among the five natural vibration modes analyzed:

- Three modes are related to bending
- Two modes are related to torsion

This distribution implies that the system is more sensitive to bending vibrations, which could be due to the shaft's slender geometry, its unsupported length, or the relative stiffness of the mounting bearings. Bending-dominant systems are more susceptible to misalignments and unbalanced loads, both of which can amplify vibrational response under certain operating conditions.

c) Frequency Proximity to Operating Harmonics

The operating frequency of the rotor, based on its rotational speed, is approximately 16.25 Hz. A critical observation from the simulation is that some of the natural frequencies—particularly the first three bending modes—are close to integer multiples (harmonics) of this base frequency. For example:

- 1st Harmonic: 16.25 Hz
- 2nd Harmonic: 32.5 Hz
- 3rd Harmonic: 48.75 Hz
- 4th Harmonic: 81.25 Hz

The first bending mode at 84.592 Hz is very close to the 4th harmonic of the rotor’s speed. This coincidence poses a serious risk of resonance, where even small excitation forces at the 4th harmonic can cause disproportionately large vibration amplitudes.

This observation aligns with findings from vibration diagnostics presented in Chapter 3, where vibration peaks near the 4th harmonic were detected during real-world operation. This strongly suggests that the natural frequency of the system is interacting with a harmonic excitation, a classic precursor to resonant behavior.

d) Risk of Resonance Due to Misalignment

In practical scenarios, shaft misalignment between the motor and turbine can introduce dynamic forces that excite the system at specific harmonics. These forces can stem from:

- Angular or parallel misalignment
- Wear or looseness in couplings
- Rotor eccentricity

Such defects often generate vibration spectra rich in harmonics of the rotational speed, particularly at even multiples (2x, 4x), which aligns with the observed proximity of the first bending modes to the 4th harmonic.

If this misalignment condition coincides with a system’s natural frequency, the resulting resonance can cause:

- Excessive vibrations
- Fatigue failure in rotating or stationary components
- Bearing damage
- Reduced efficiency and increased maintenance costs

e) Conclusion and Diagnostic Insight

Based on the simulation results and their correlation with operational diagnostics:

- The rotor–pump system exhibits modal behavior that makes it prone to bending resonance at frequencies near 84–86 Hz.
- These frequencies coincide with the 4th harmonic of the system's rotational speed, suggesting a potential resonance hazard, particularly under misalignment or imbalance conditions.

- The frequent occurrence of bearing defects observed on this machine can therefore be explained by the overlap between natural frequencies and excitation frequencies, a well-known root cause of dynamic failures.

To mitigate this risk, design or maintenance measures should be considered, such as:

- Improving shaft alignment and support stiffness
- Introducing damping to reduce resonance amplitude
- Adjusting operational speeds to avoid critical harmonics
- Modifying geometry or materials to shift natural frequencies away from excitation ranges

These insights underscore the value of modal analysis as a predictive maintenance and design tool in the early detection and avoidance of vibration-related failures.

4.7.1 Recommended Solutions

To reduce the risk of resonance and improve the vibrational performance of the rotor–pump assembly, several corrective measures are proposed based on the results of the modal analysis and observed dynamic behavior:

- Redesign the coupling between the motor shaft and the turbine shaft, and replace the current semi-elastic coupling with a fully elastic coupling. An elastic coupling provides greater flexibility in absorbing misalignment, damping vibration transmission, and reducing the excitation of natural frequencies. This change can significantly lower the likelihood of resonance and mechanical fatigue.
- Reevaluate the sizing and selection of the bearings. It is recommended to choose bearings that are better suited for the system's dynamic loads, especially those that offer higher stiffness, better damping capabilities, and improved resistance to misalignment. An optimized bearing design contributes to reduced vibration amplitudes and increased system reliability.
- Introduce damping mounts (anti-vibration pads or isolators) at the machine’s support points. These mounts help absorb and dissipate shocks and vibrations transmitted through the machine’s structure. By isolating the machine from its mounting base, these components effectively reduce structural vibrations and limit the propagation of resonance through the frame.

4.8 Numerical Simulation Using Ansys:

4.8.1 Results of the System Simulation with Ansys:

The results of the numerical simulation using Ansys (modal analysis) of the finisher pump are summarized in Table 4-4. We considered only the first five vibration modes in order to compare them with those obtained using SolidWorks.

The modal deformations of the system are shown in Figures 4-9 through 4-13, illustrated as follows:

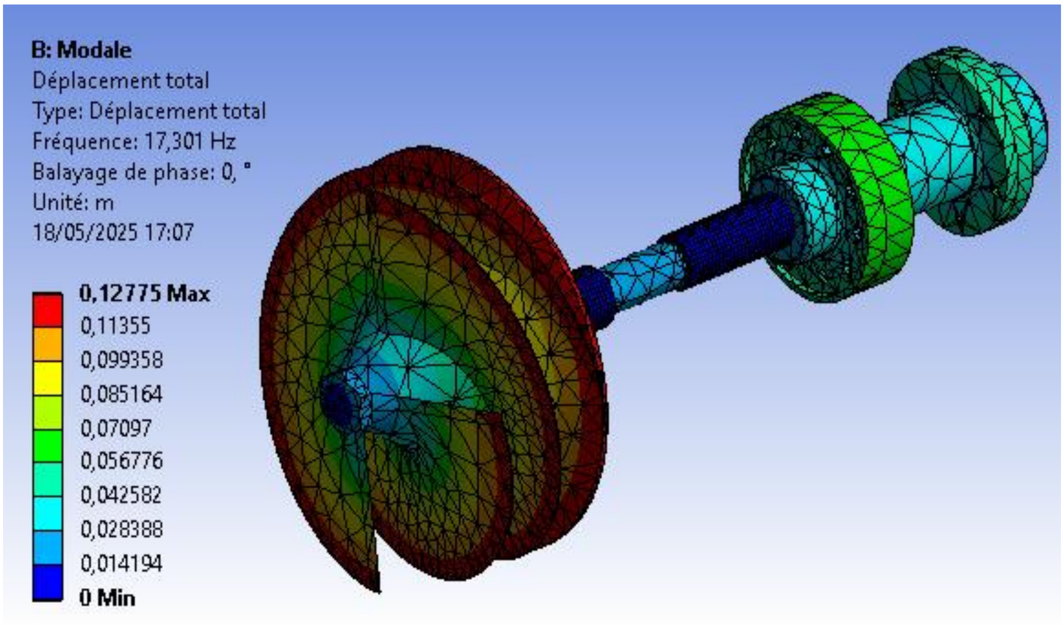

Figure 4-9: First vibration mode at a frequency of 17.301 Hz.

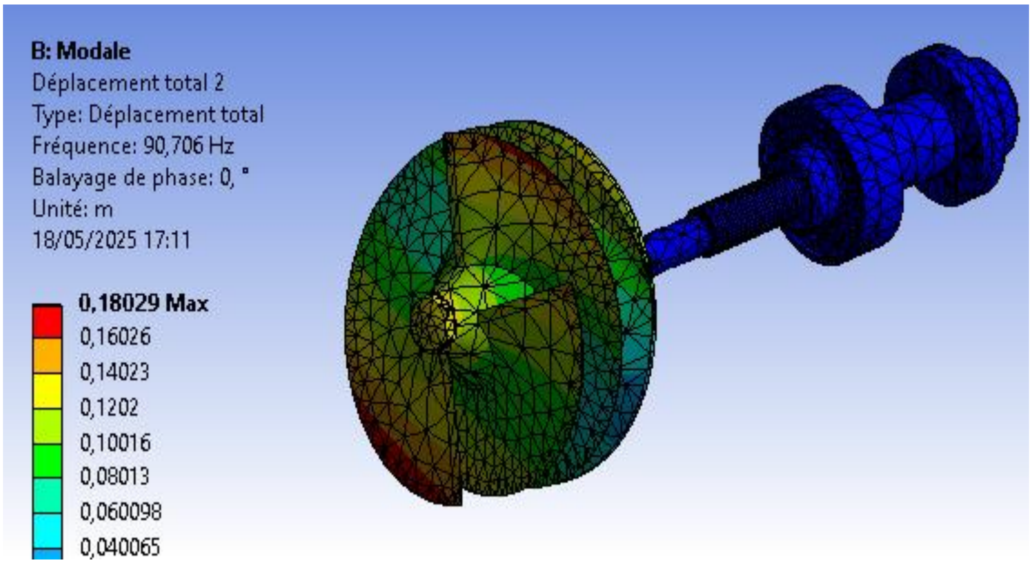

Figure 4-10: Second vibration mode at a frequency of 90.706 Hz.

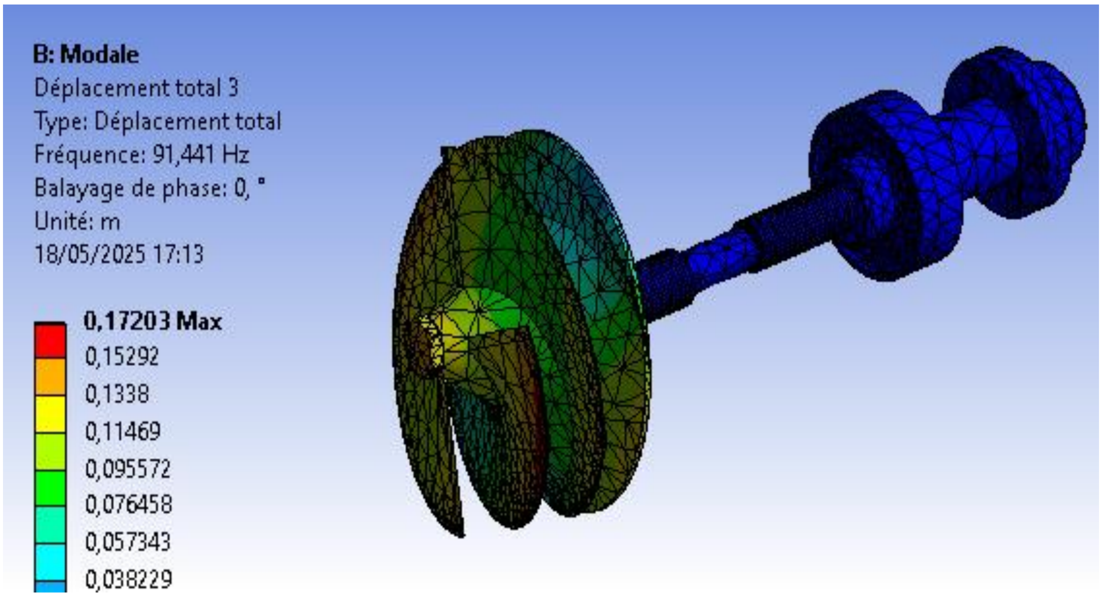

Figure 4-11: Third vibration mode at a frequency of 97.441 Hz.

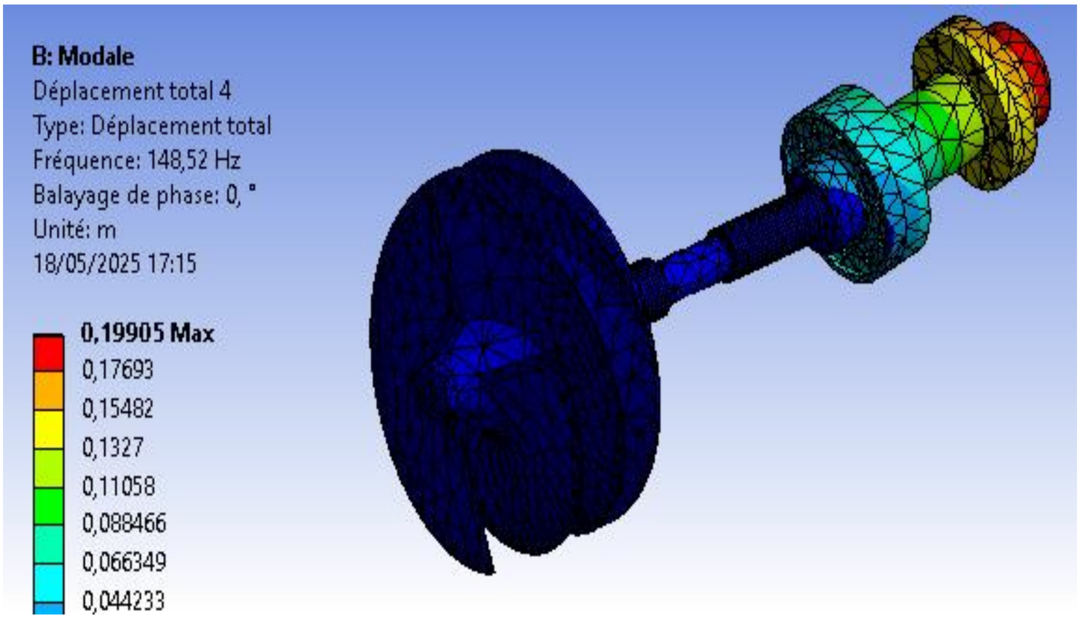

Figure 4-12: Fourth vibration mode at a frequency of 148.52 Hz.

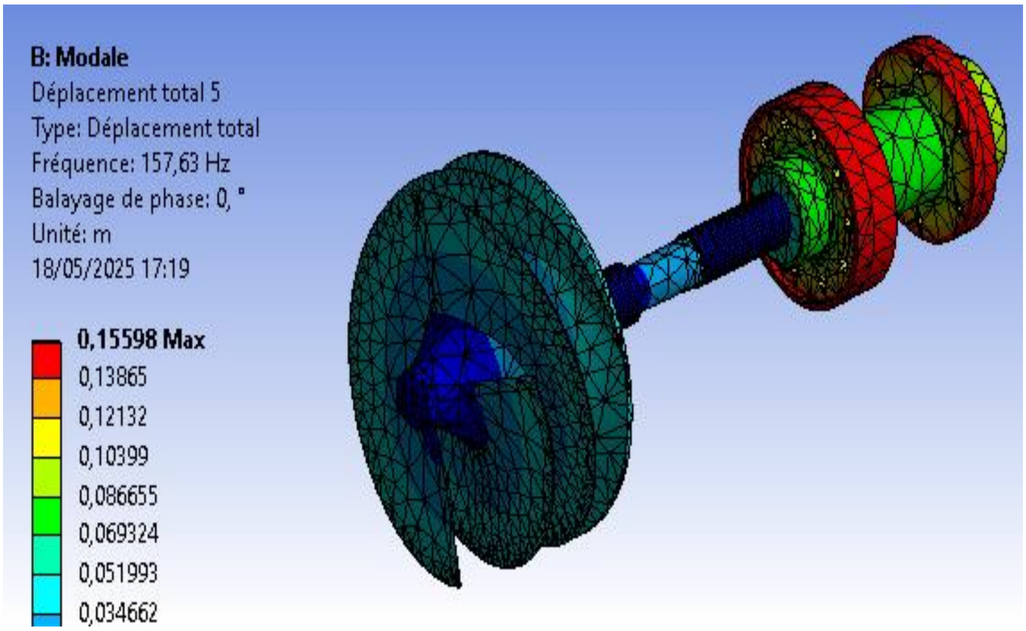

Figure 4-13: Fifth vibration mode at a frequency of 157.63 Hz.

N° mode	Natural angular frequency (rad/s)	Natural frequency (Hz)
1	**108,65**	**17,301**
2	**569,63**	**90,706**
3	**574,25**	**91,441**
4	**932,71**	**148,52**
5	**989,92**	**157,63**

Table 4-4: List of the system's natural frequencies from Ansys.

4.8.2 Interpretation of the Simulation Results:

The results of the numerical simulation using Ansys (modal analysis) of the system are summarized in Table 4-4. We observe that:

- The first vibration mode (17.301 Hz) is a torsional mode.
- The second and third vibration modes, occurring at frequencies of 90.706 Hz and 97.441 Hz, respectively, are bending modes.
- The fourth and fifth vibration modes are torsional modes.

4.9 Comparison and Validation of the Numerical Results with the Experimental Data:

The mechanical defects detected during the operation of the finisher pump are mainly due to misalignment between the motor shaft and the turbine shaft, causing bearing faults in both bearings supporting the turbine rotor, as well as clearance in the coupling fingers. This clearance is evidenced by the presence of harmonics, in the form of a component at the base frequency of 16.25 Hz (see Figure 4-5), which corresponds to the rotational speed of the pump rotor.

Accordingly, we present these various results in Table 4-5:

Natural frequency number (natural mode)	solidworks (Hz)	par ANSYS (Hz)	Frequency experimentally in Hz	
			Base frequency of the electric motor (16.25)	Bearing fault frequency (138.75) (Figure 4-6)
1	84.592	17,301	16.25 Hz base frequency of the motor and that of the pump 81.25 Hz Fourth harmonic of the base frequency	
2	85.956	90,706	81.25 Hz Fourth harmonic of the base frequency 97,50 Hz Fifth harmony of the base frequency	
3	86.272	91,441	81.25 Hz Fourth harmony of the base frequency 97.50 Hz Fifth harmony of the base frequency	

4	183.1	148,52	146.25 Hz Eighth harmony of the fundamental frequency 178.75 Hz Tenth harmony of the fundamental frequency.	138.75 Hz Frequency related to the bearing cage.
5	187.03	157,63	162.5 Hz Ninth harmony of the base frequency. 178.75 Hz Tenth harmony of the base frequency. 195 Hz Eleventh harmony of the base frequency.	138.75 Hz Frequency related to the bearing cage.

Table 4-5: Comparison of Numerical Simulation Results with Experimental Data

Commentary:

The numerical simulation results align with the frequencies detected experimentally, particularly those generated by misalignment, its resulting shocks, and related harmonics. It is observed that frequencies caused by bearing faults appear at higher frequencies, suggesting a high probability of coincidence with the natural frequencies associated with higher-order modes (mode 4 and above, as shown in Table 4-5).

According to the SolidWorks simulation, the vibration modes begin with bending modes. In this case, **three (3)** bending vibration modes and **two (2)** torsional vibration modes were detected.

In contrast, the Ansys simulation shows that the first mode is torsional, with **three (3)** torsional vibration modes and **two (2)** bending vibration modes identified.

From both simulations, we observe that among the five (5) vibration modes, the system exhibits both bending and torsional behaviors. The number of bending and torsional modes is approximately the same in both simulations.

4.10 Proposed Solutions :

- Reconsider the design of the coupling connecting the motor shaft to the turbine shaft, and opt for a fully elastic coupling instead of a semi-elastic one.
- Reevaluate the dimensioning and type of bearings used, and select more appropriate models.
- Use damping mounts at the machine’s mounting points to absorb shocks generated by vibrations propagating through the machine structure.

4.11 Conclusion:

The examination of all identified mode shapes allows us to conclude that the natural frequencies of the system are generally close to the operating frequencies of the installation. This proximity is observed across almost all vibration modes. Under normal conditions, this does not necessarily lead to problems; however, in the presence of mechanical defects or degradation—such as misalignment, imbalance, or bearing wear—these frequencies may coincide, potentially causing resonance, which poses a significant risk to the safe operation of the machine.

The numerical simulation performed using SolidWorks has proven to be an essential tool for identifying and analyzing these critical conditions. By simulating the vibrational behavior of the system, we are able to:

- Detect potential resonance zones before physical testing or deployment,
- Understand the dynamic response of the structure under real-world operating conditions,
- Evaluate the effect of various design parameters and boundary conditions,
- Propose effective corrective actions to mitigate vibrational issues.

Thanks to this simulation-based approach, we can significantly reduce the likelihood of mechanical failures, improve operational reliability, and extend the system’s service life. Moreover, the ability to predict failure modes before they occur allows engineers to implement preventive design modifications and maintenance strategies tailored to the system's actual dynamic behavior.

In summary, the use of advanced simulation tools such as SolidWorks not only enhances the accuracy of vibration analysis but also plays a key role in improving the overall robustness and safety of mechanical systems.

General conclusion

The study presented in this report focused on the experimental, **numerical simulation and modal analysis** of the rotor–pump finisher system using:

- **on-site experimentation**,
- **SolidWorks Simulation**
- **Ansys**
- a powerful finite element analysis (FEA) tool.

The **modal analysis** allowed us to identify the system's first five natural frequencies and their corresponding vibration modes. The results revealed that **three modes were dominated by bending**, and **two by torsional deformation**, indicating a structural tendency toward bending vibrations. Importantly, several natural frequencies were found to be **close to the operating harmonics** of the rotor (notably the 4th harmonic), which poses a risk of **resonance**, particularly under conditions of mechanical defects such as misalignment or bearing wear.

The **simulation results** demonstrated a strong correlation with real-world vibration diagnostics, confirming that **resonance phenomena** are likely contributing to the recurrent mechanical issues observed on the machine. These findings highlight the importance of predictive analysis in modern engineering workflows.

Based on the outcomes of the analysis, several **corrective actions** were recommended, including:

- Redesigning the shaft coupling with an elastic element to better absorb dynamic loads,
- Optimizing the bearing selection and sizing to enhance system stability,
- Implementing vibration-damping mounts at structural support points.

Ultimately, this study demonstrates the effectiveness of using **finite element simulation** to evaluate and improve the mechanical reliability of rotating machinery. The approach not only helps **reduce failure rates**, but also supports the **design of safer, more robust systems**, and guides preventive maintenance strategies.

Through this work, we conclude that **numerical simulation is a key tool** in the diagnosis, design optimization, and predictive maintenance of mechanical systems operating under dynamic conditions.

References

[1] [Mobley, R. K. (2002). An Introduction to Predictive Maintenance. Butterworth-Heinemann.

[2] Randall, R. B. (2011). Vibration-based Condition Monitoring: Industrial, Aerospace and Automotive Applications. Wiley.

[3] Jardine, A. K. S., Lin, D., & Banjevic, D. (2006). A review on machinery diagnostics and prognostics implementing condition-based maintenance. Mechanical Systems and Signal Processing, 20(7), 1483–1510.

[4] Gulati, R., & Smith, R. (2009). Maintenance and Reliability Best Practices. Industrial Press.

[5] Lei, Y., Li, N., Guo, L., Li, N., Yan, T., & Lin, J. (2020). Machinery Health Prognostics: A Systematic Review from Data Acquisition to RUL Prediction. Mechanical Systems and Signal Processing, 104761.

[6] R. Magraoui , A.Zemirline Adel and M.Ouali, (2024). Improvement of the performance of an industrial wringer, RGSA –Revista de Gestão Social e Ambiental, ISSN : 1981-982X, DOI : https://doi.org/10.24857/rgsa.v18n12-038

[7] R. Magraoui and M.Ouali, (2024). Contribution to Conditional Maintenance by Vibration Analysis of Rotating Machine Mechanical Failures and Proposed Solutions, RGSA –Revista de Gestão Social e Ambiental,

ISSN: 1981-982X, DOI: https://doi.org/10.24857/rgsa.v18n10-052.

[8] Muszynska, A. (2005). Rotordynamics. CRC Press.

[9] ISO 20816-1:2016. Mechanical vibration – Measurement and evaluation of machine vibration – Part 1: General guidelines.

[10] Abderrahmane MECHTI, Amir BOUDJEDOUB, Predictive Maintenance of Rotating Machine. Application to the cellulose shredder BD 07, Project Graduation for Obtaining the Master’s Degree in Mechanical construction, U.Blida 1 Mechanical department .2019/2020

[11] Dassault Systèmes. SolidWorks Simulation User Guide. Dassault Systèmes, 2023.

[12] Inman, Daniel J. Engineering Vibration. 5th ed., Pearson, 2014.

[13] Cook, Robert D., Malkus, David S., Plesha, Michael E., and Witt, Robert J. Concepts and Applications of Finite Element Analysis. 4th ed., Wiley, 2002.

[14] Bendali Amir et Behili Youcef, Diagnostic par l’analyse vibratoire étude et conception d’un ventilateur centrifuge, Mémoire de Master Fabrication Mécanique et Productique, Département de Mécanique U. Blida1, 2019.

[15] Bendar Fouad , Bensalah Yacine, Etude et conception ventilateur centrifuge, Mémoire de Master Fabrication Mécanique et Productique, Département de Mécanique U. Blida1, 2024.

[16] Amrani Abderrahmane , El Aichi Mohamed Abdelbasset , Kasri Mohamed Amine, Centrifugal fan aérodynamique and rotor Dynamic study, Mémoire de Master Construction Mécanique et Productique, Département de Mécanique U. Blida1, 2021.

Useful Links

[L1] https://boilersinfo.com/centrifugal-pump-components/

[L2] (https://www.legarrec.com/entreprise/differentes-pompes-industrielles/)

APPENDIX

République Algérienne Démocratique et Populaire
Ministère de l'enseignement supérieur et de la recherche scientifique
UNIVERSITE DE BLIDA1
FACULTE DE TECHNOLOGIE
DEPARTEMENT DE MECANIQUE

Attestation de Stage

Je, soussigné(e) (Le responsable de stage) M. Missoum Ahmed

Que l'étudiant (e) Senoun IMADeddine né(e) 15/08/2001 à Bir mourad rais

Inscrit (e)au Département de Mécanique, Faculté de Technologie, Université deBlida1

A effectué (e) un stage de fin de formation dans la filière : Génie Mécanique

A (l'établissement, administrations, Sociétés) : SIM conserverie

Durant la période du : 15 Février 2021 au 07 Mars 2021

Fait à Blida le 22/05/2021

Le responsable de l'établissement de L'enseignement ou de la formation supérieur	Le responsable de l'établissement de l'Administration d'accueil

SPA AQUA SIM BLIDA — Z.I Centre BEN-BOULAID - BLIDA

MISSOUM Ahmed — Directeur d'Unité

République Algérienne Démocratique et Populaire
Ministère de l'enseignement supérieur et de la recherche scientifique
UNIVERSITE DE BLIDA1
FACULTE DE TECHNOLOGIE
DEPARTEMENT DE MECANIQUE

Attestation de Stage

Je, soussigné(e) (Le responsable de stage) M. Missoum Ahmed

Que l'étudiant (e) Bougofla AKRAM né(e) 11/01/1997 à DJAMAA ELMGHAIR

Inscrit (e)au Département de Mécanique, Faculté de Technologie, Université deBlida1

A effectué (e) un stage de fin de formation dans la filière : Génie Mécanique

A (l'établissement, administrations, Sociétés) : SIM conserverie

Durant la période du : 15 Février 2025 au 07 Mars 2025

Fait à Blida le 22/04/2025

Le responsable de l'établissement de L'enseignement ou de la formation supérieur

Le responsable de l'établissement de l'Administration d'accueil

SPA AQUA SIM BLIDA — Z.I Centre BEN-BOULAID BLIDA

MISSOUM Ahmed
Directeur d'Unité

RAPPORT DE STAGE effectué au sein de l'entreprise AQUA SIM

De 15 février à 7 Mars

Réalisé par les étudiant :

Sennoun Imad Eddine

Bougoffa Akram

2024/2025

Remerciement

Avant tout développement sur cette expérience professionnelle, il apparaît opportun de commencer ce rapport de stage par des remerciements, à ceux qui m’ont beaucoup appris au cours de ce stage, et même à ceux qui ont eu la gentillesse de faire de ce stage un moment très profitable.

Aussi, je remercie M.Missoum , mon maître de stage qui m’a formé et accompagné tout au long de cette expérience professionnelle avec beaucoup de patience et de pédagogie. Enfin, je remercie l’ensemble des employés d’Atelier de maintenance pour les conseils qu’ils ont pu me prodiguer

Présentation de l’entreprise

Nom de l’entreprise : Conserverie SIM

Localisation : Zone Industrielle Centre, Blida, Algérie

Secteur d’activité : Industrie agroalimentaire

Produits : Concentré de tomates, conserves de légumes, confitures, boissons, pâtes, couscous.

1. Introduction :

Ce rapport présente mon expérience de stage effectué au sein de la Conserverie SIM, une entreprise spécialisée dans la transformation agroalimentaire, notamment la fabrication de concentré de tomates. Ce stage m'a permis d'approfondir mes connaissances techniques en observant et intervenant sur une pompe utilisée dans la chaîne de production.

2. Objectifs du stage :

- Découvrir le fonctionnement d'une chaîne de production agroalimentaire.
- Étudier la pompe utilisée dans la transformation de la tomate.
- Identifier les pannes possibles et les techniques d'entretien ou de réparation.

3. Description de la pompe et son rôle :

Dans le cadre de ce projet, nous nous sommes intéressés à une pompe centrifuge installée au sein d'une conserverie de tomate SIM, cette pompe joue le rôle de finisseur dans leur chaine de production. Cette pompe ayant subi un défaillance mécanique importante, des bruits un inhabituels accompagnes de fortes vibrations ont été détectée. Ce défaut a eu pour conséquence un désalignement progressif de l'arbre, usure des potées de roulement et de des défauts de roulement. Ces symptômes ont conduit à l'arrêt de la machine afin d'éviter des dommages plus graves.

La pompe finisseur est une pompe centrifuge, un équipement essentiel dans la chaine de production pour le transfert de fluides. Son rôle principal est d'aspirer la pâte de tomate à travers une conduite d'entrée (aspiration)de bas d'une citerne de stockage, puis de le refouler à une pression plus élevée à travers une conduite de sortie vers le haut de citerne et avec la présence de vapeur permettre de sèche la pâte et augmente le facteur Brix jusqu'à 36. Le fonctionnement repose sur la rotation d'une roue (ou empailleur) qui transmet de l'énergie cinétique au fluide, convertie ensuite en énergie de pression grâce à la géométrie du corps de pompe.

4. Activités réalisées :

- Observation du fonctionnement de la pompe pendant la production.
- Participation au démontage et au nettoyage.
- Diagnostic d'une panne (fuite, vibration anormale, usure de joint, etc.).
- Remplacement de pièces (joints, garnitures mécaniques, roulements...).
- Suivi de la procédure de remise en service.

5. Compétences développées :

- Lecture de plans techniques et de schémas de pompes.
- Utilisation d'outils de maintenance industrielle.
- Respect des normes d'hygiène et de sécurité en industrie agroalimentaire.
- Travail en équipe avec les techniciens de maintenance.

6. Conclusion :

Ce stage m'a permis de découvrir l'environnement industriel agroalimentaire et de mieux comprendre le rôle crucial des équipements comme les pompes dans une chaîne de production. Il a enrichi mes compétences techniques et renforcé mon intérêt pour la maintenance industrielle.