ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)
INGENIERO INDUSTRIAL

OPTIMIZATION OF A BUCKET ELEVATOR: DESIGNING THE TESTING BENCH AND PROTOCOL

Autor: Jose Antonio López Cabezas
Director: Dr. Stephen Zahos

Madrid
Julio 2018

JOSE ANTONIO
LOPEZ
CABEZAS

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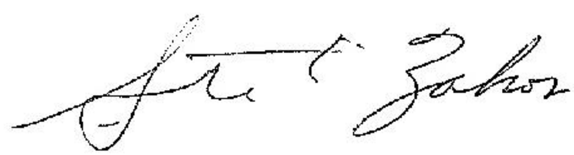

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OPTIMIZATION OF A BUCKET ELEVATOR: DESIGNING THE TESTING BENCH AND PROTOCOL

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OPTIMIZATION OF A BUCKET ELEVATOR: DESIGNING THE TESTING BENCH AND PROTOCOL

RESUMEN DEL PROYECTO

Autor: Jose Antonio López Cabezas

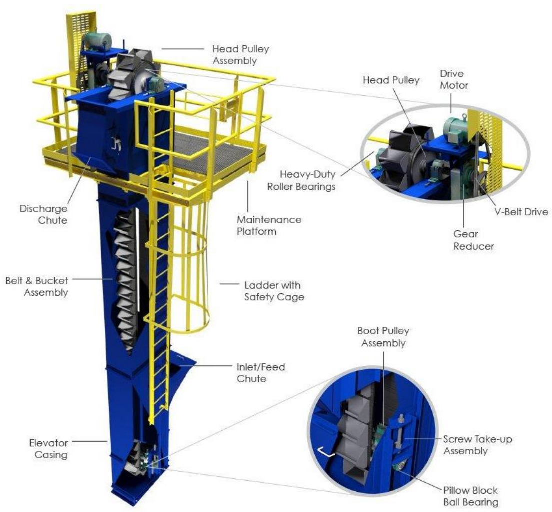
Director: Prof. Stephen Zahos

Nombre del Proyecto: Optimization of a Bucket Elevator: Designing the Test Bench and Protocol

Institución colaboradora: University of Illinois, Universidad del Norte de Colombia, Superbrix S.A., Universidad Pontificia Comillas.

1. Introducción y metodología

SuperBrix SA es una empresa dedicada a la fabricación de maquinaria para la industria agroalimentaria. Planea hacer mejoras en el diseño de sus elevadores de cangilones, destinados al procesamiento de arroz. Los elevadores de cangilones son un elemento común en el procesamiento de todo tipo de granos y de muchos otros tipos de materiales. Un solo grano de arroz pasa por unos 12 elevadores durante su procesado,



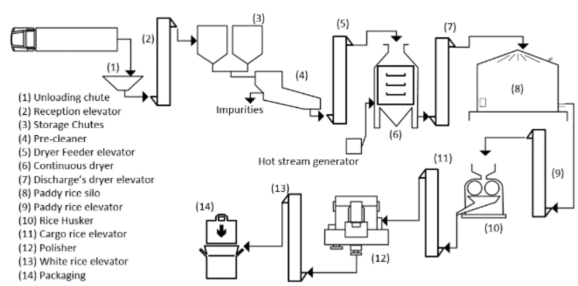


Figura 1 y 2. Elevador de canguilones [8] y Esquema ilustrativo del procesado de arroz

El objetivo del cliente es hacer que sus productos sean competitivos en un mercado que mejora continuamente. Después de un proceso iterativo de resolución de problemas, y de barajar varias opciones como el uso de software para modelación de elementos discretos (DEM), se ha resuelto por razones de costes y operatividad, diseñar un banco y un protocolo de pruebas físico para evaluar las variables que apuntan a mejorar el rendimiento de los elevadores de cangilones. Se debe minimizar el daño que sufre el arroz durante su proceso de producción, ya que hace que se devalúe su precio de mercado. Las variables a estudiar han sido establecidas por Superbrix y son: la velocidad de operación, la geometría de la cabeza, el tipo de cubo, y el espaciado entre ellos.

Para el diseño del banco de pruebas se realizaron investigaciones de estudios y experimentos previos relacionados con el diseño y la función actuales de los elevadores de cangilones. Con esta información, se realizaron cálculos físicos y mecánicos básicos sobre el rendimiento teórico, especialmente con respecto a la geometría de la cabeza. Después de completar estos cálculos, el banco de pruebas se diseñó conceptualmente a partir bocetos y se rediseñó en SolidWorks, un software de diseño 3D CAD y aprobado por el cliente. Además, con la ayuda del cliente, se completó una lista de materiales y una revisión de las patentes.

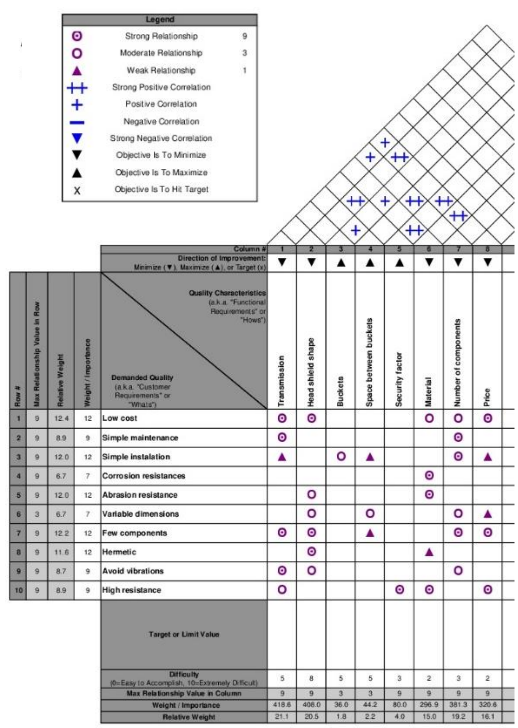
Siguiendo el diseño del banco de pruebas, se desarrolló el protocolo de prueba correspondiente. Se realizó un análisis detallado de la industria de procesamiento de arroz, las propiedades del arroz y las técnicas de muestreo. La investigación incluyó entrevistas con profesionales en el campo del procesamiento de arroz y consultas a profesores del departamento. El protocolo de prueba fue diseñado para ser efectivo, rápido y preciso. Después de compilar los hallazgos, se ha entregado un informe completo y una presentación a que permitirá a Superbrix agregar valor a sus productos y a sus recomendaciones y asesoramiento a sus clientes.

Al completar los objetivos, las partes se integraron en un documento completo que incluye planos, archivos CAD y anexos. El documento fue organizado para ser fácilmente comprensible por el equipo de diseño de SuperBrix y los operadores.

2. Diseño del banco de pruebas

Las especificaciones para el diseño del banco fueron definidas junto al jefe del equipo de diseño de Superbrix. Se han usado herramientas de ayuda para diseños conceptuales como la matriz de comparación por pares (Pairwise comparison matrix), la matriz QFD (Quality function deployment) o los diagramas de caja negra y caja transparente.

Pairwise Comparison		1 Low Cost	2 Simple Maintenance	3 Simple Installation	4 Corrosion Resistance	5 Variable Dimensions	6 Abrasion Resistance	7 Few Components	8 Hermetic	9 Avoid Vibrations	10 High Resistance	Sum	Relativ Weigh
1	Low Cost		7	6	8	5	8	5	6	4	7	56	12.44%
2	Simple Maintenance	3		3	6	4	6	4	3	6	5	40	8.89%
3	Simple Installation	4	7		7	5	7	5	6	7	6	54	12.00%
4	Corrosion Resistance	2	4	3		3	5	3	2	4	4	30	6.67%
5	Variable Dimensions	5	6	5	7		7	6	6	6	6	54	12.00%
6	Abrasion Resistance	2	4	3	5	3		3	2	4	4	30	6.67%
7	Few Components	5	6	5	7	4	7		7	7	7	55	12.22%
8	Hermetic	4	7	4	8	4	8	3		7	7	52	11.56%
9	Avoid Vibrations	6	4	3	6	4	6	3	3		4	39	8.67%
10	High Resistance	3	5	4	6	4	6	3	3	6		40	8.89%
TOTAL												450	100.00%



Figuras 3 y 4. Matriz de comparación por pares y matriz QFD

Para cada función que debía realizar el banco de pruebas, se evaluaron las ventajas y las desventajas de las distintas soluciones de diseño para dar respuesta a estas funciones. Los puntos clave a estudiar fueron: carga y descarga del arroz, variación de la geometría de la cabeza, motor y transmisión y sistema de variación de velocidad. La solución se muestra en la *figura 5* a modo de tabla.

Function	**Conceptual solution 1**	**Conceptual solution 2**	**Conceptual solution 3**
Rice storage and loading	Box with switch	Manual inlet	
Allow head's geometry variation	Adjustable head with rails	Modular head	
Shaft's rpm variation	Variable frequency drive	Gearbox	
Transmit torque to the shaft	Belt	Chain	Gear

Figura 5. Tabla morfológica de diseño

Como consecuencia de este método de diseño y por exigencias del proyecto, se propusieron 3 alternativas de diseño de este banco de pruebas (véase *figura 6*) . Con las distintas soluciones propuestas a las opciones:

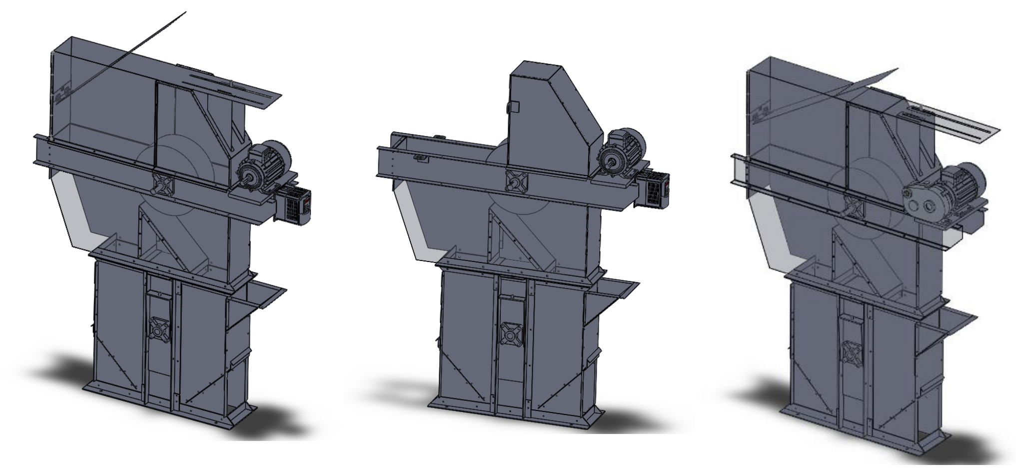
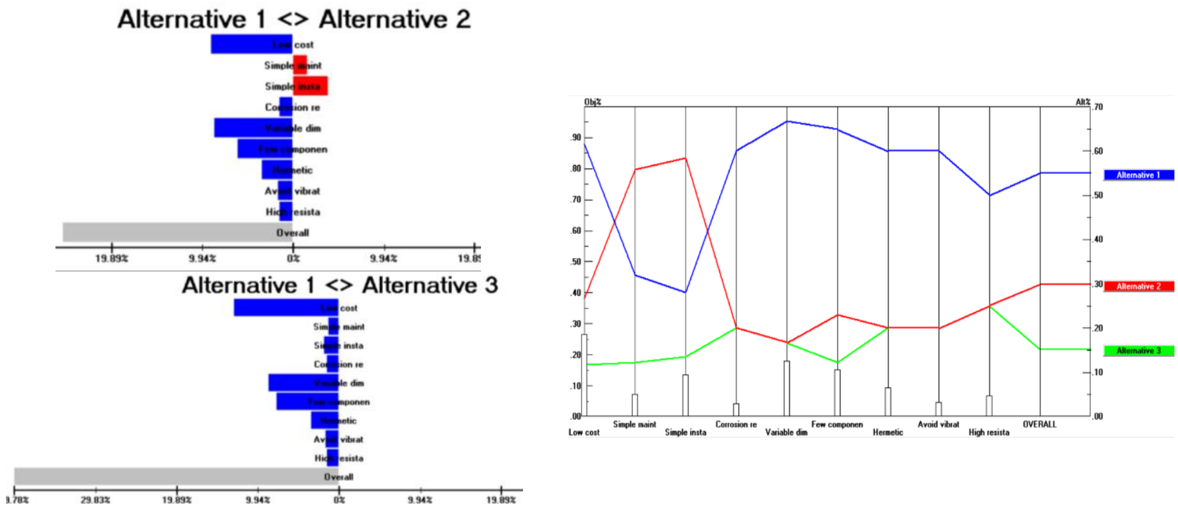


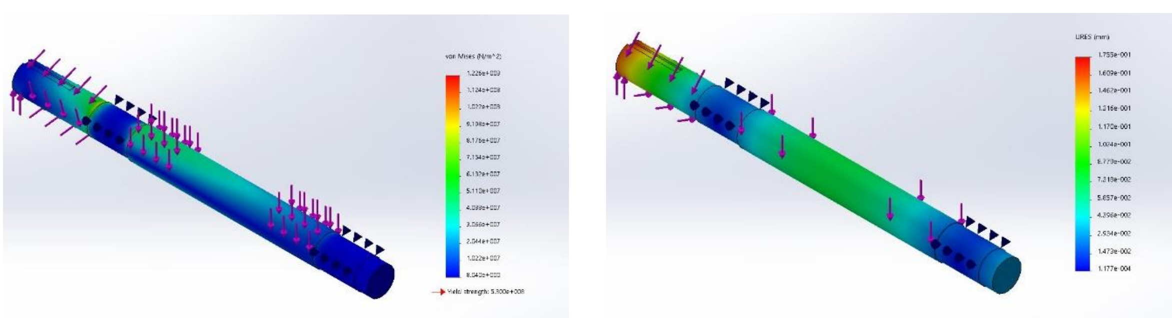
Figura 6. Alternativas de diseño presentadas

Para la selección del modelo más adecuado se utilizó una herramienta de selección analítica y racional, el software Expert Choice®, que emplea un proceso analítico jerárquico (AHP, Analytic Hierarchy Process) y se consultó con el equipo de diseño de Superbrix. La alternativa seleccionada fue la primera por un funcionamiento general superior y más práctico



Figuras 7 y 8. Evaluación de las alternativas por el software Expert choice.

Tras la selección del diseño, se realizaron todos los cálculos mecánicos necesarios para la selección de los componentes. Junto con el diseño en CAD, ésta ha sido una de las partes con más carga de trabajo del proyecto por su proceso iterativo. La mayoría de los métodos han sido extraídos de manuales especializados, recomendaciones de profesores y consejos del cliente. Los cálculos han sido divididos en las siguientes secciones: Condiciones del cliente, potencia y par, selección de rodamientos, selección de cadena, acople del tambor de polea, diseño del eje y selección de la correa. Se ha profundizado especialmente en el diseño del eje por peticiones del profesor, usando SolidWorks para comprobar los resultados de los cálculos hechos previamente.



Figuras9 y 10. Cargas estáticas y deformación del eje. SolidWorks

3. Diseño del protocolo de pruebas

Se ha proporcionado toda la información pertinente para la prueba y el análisis del daño del arroz. Incluye una descripción general de las propiedades del arroz y las variables a estudiar, un procedimiento de prueba detallado y recomendaciones para el análisis de datos. Los estándares ISO 7301 y Codex 198 han sido consultados para el desarrollo del proceso de test y el desarrollo de procedimientos.

Se incluyen además las instrucciones para realizar las pruebas y el material de laboratorio necesario para ello. La tabla 10 es una captura del documento de Excel creado como hoja de toma de datos estadística para el análisis de la información. En la hoja de cálculo se encuentran los factores de clasificación de calidad del grano

Technician		TESTING RECORDS FOR TEST BENCH				
Date						
Grain Type		Sample	Trial 1	Trial 2	Trial 3	Trial Avg.
		A				
Initial Testing	Weight (g)		–	–	–	–
	Large brokens (g)	–				0
	Medium brokens (g)	–				0
	Small brokens (g)	–				0
	Moisture Content (%)		–	–	–	–
	Temperature (°C)		–	–	–	–
	Velocity (Hz)		–	–	–	–
	Head Angle (deg)		–	–	–	–
		B				
Final Testing	Weight (g)		–	–	–	–
	Large brokens (g)	–				0
	Medium brokens (g)	–				0
	Small brokens (g)	–				0

Tabla 10. Captura de la hoja de cálculo de análisis de datos

GRADING FACTORS	GRADE PREMIUM: 1: 2: 3
Head Rice (Min %)	95.00:80.00:65.00:50.00
Large Brokens (Max %)	3.00: 10.00: 10.00:20.00
Broken Other than Large Brokens (Max %)	1.90: 9.75:24.00:29.00
Brewers (Max %)	0.10: 0.25: 0.50: 1.00
Defectives:	
Damaged Kernels (Max %)	- : 0.25:0.50: 2.00
Discolored Kernels (Max %)	0.50: 2.00: 4.00: 8.00
Chalky & Immature Kernels (Max %)	2.00: 5.00: 10.00: 15.00
Contrasting Types (Max %)	3.00: 6.00: 10.00: 18.00
Red Kernels (Max %)	- : 0.25: 0.50: 2.00
Red Streaked Kernels (Max %)	1.00: 3.00: 5.00: 10.00
Foreign Matter (Max%)	- : 0.10: 0.20: 0.50
Paddy (Max. no. per 1000 grams)	1 : 8 :10 :15
Moisture Content (Max %)	14.00: 14.00: 14.00: 14.00

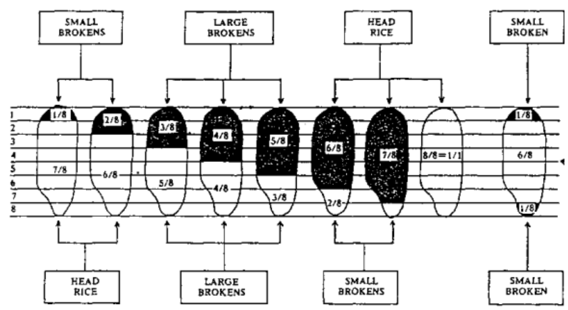


Figura 11 y 12. Clasificación del grano en función del daño [21]

4. Conclusiones y recomendaciones

Del estudio realizado, se concluyó que el rendimiento del equipo y la calidad final del arroz depende de los parámetros geométricos y operativos. La velocidad de operación debe ser la primera consideración, así como el diámetro de la polea, estos dos factores determinarán la energía cinética del grano, que se traducirá en la fuerza de impacto. La geometría de la cabeza también es importante, especialmente si las velocidades de operación son altas, en este caso, la cabeza será la superficie de impacto donde rebotará el grano y se producirá el daño. Como predicción, una geometría de la cabeza parabólica o curva se comportará mejor debido a la trayectoria parabólica del grano. La geometría del canguilón influye en las trayectorias dado que las fuerzas presentes a lo largo del lanzamiento tienen en cuenta el ángulo de salida de la pared exterior del cucharón. El espacio entre cubos influirá en la capacidad y la potencia requerida, pero probablemente no en el daño causado al grano.

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PROJECT SUMMARY

Author: Jose Antonio López Cabezas

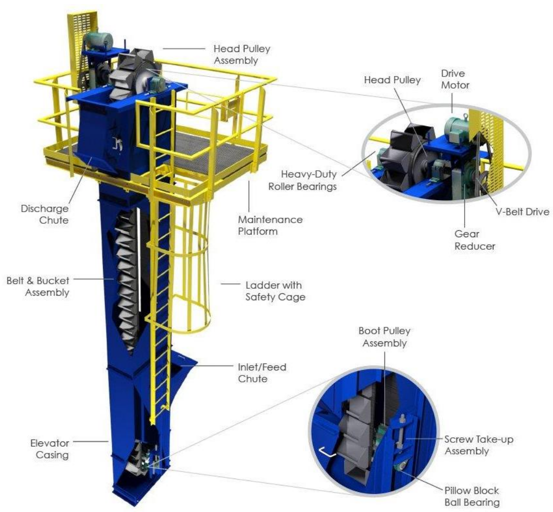
Director: Prof. Stephen Zahos

Project name: Optimization of a Bucket Elevator: Designing the Test Bench and Protocol

Collaborating institution: University of Illinois, Universidad del Norte de Colombia, Superbrix S.A., Universidad Pontificia Comillas.

1. Introduction and methodology

SuperBrix SA is a company dedicated to the manufacture of equipment for the agri-food industry. It plans to make improvements in the design of its bucket elevators, destined to the processing of rice. Bucket elevators are a common element in the processing of all types of grains and many other types of materials. A single grain of rice goes through about 12 elevators during processing,



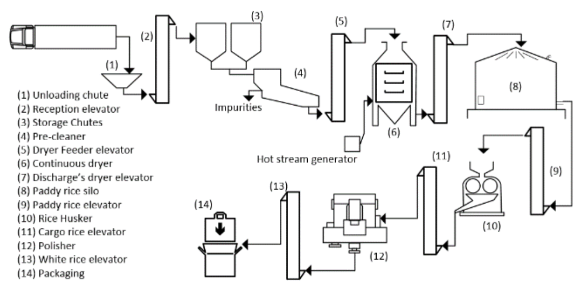


Figure 1 and 2. Bucket elevator [8] and rice processing scheme

The client's goal is to make their products competitive in a market that improves continuously. After an iterative problem solving process, and considering several options such as the use of software for discrete element modeling (DEM), it has been decided for reasons such as costs and operability, the design of a test bench and test protocol to evaluate the variables that aim to improve the performance of bucket elevators. The damage suffered by rice during its processing must be minimized, and its market price devalued. The variables to be studied have been established by Superbrix and are: the operating speed, the geometry of the head, the type of bucket, and the spacing between them.

For the design of the test bench, research studies and previous experiments related to the current design and function of the bucket elevators were carried out. With this information, basic physical and mechanical calculations were made on the theoretical performance, especially with respect to the geometry of the head. After completing these calculations, the test bench was conceptually designed from sketches and redesigned in SolidWorks, a 3D CAD design software approved by the client. In addition, with the help of the client, a list of materials and a revision of the patents were completed.

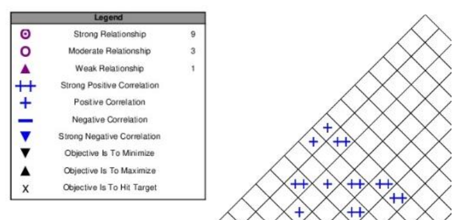
Following the design of the test bench, the corresponding test protocol was developed. A detailed analysis of the rice processing industry, rice properties and sampling techniques was carried out. The research included interviews with professionals in the field of rice processing and consultations with department professors. The test protocol was designed to be effective, fast and accurate. After compiling the findings, a complete report and a presentation have been delivered that will allow Superbrix to add value to its products and advices to its clients.

Upon completion of the objectives, the parts were integrated into a complete document that includes drawings, CAD files and annexes. The document was organized to be easily understandable by the SuperBrix design team and the operators.

2. Design of the test bench

The specifications for the test bench design were defined together with the head of the Superbrix design team. Analytical tools have been used for conceptual designs such as the Pairwise Comparison matrix, the QFD (Quality function deployment) matrix or the black box and transparent box diagrams.

	Pairwise Comparison	1 Low Cost	2 Simple Maintenance	3 Simple Installation	4 Corrosion Resistance	5 Variable Dimensions	6 Abrasion Resistance	7 Few Components	8 Hermetic	9 Avoid Vibrations	10 High Resistance	Sum	Relative Weight
1	Low Cost		7	6	8	5	8	5	6	4	7	56	12.44%
2	Simple Maintenance	3		3	6	4	6	4	3	6	5	40	8.89%
3	Simple Installation	4	7		7	5	7	5	6	7	6	54	12.00%
4	Corrosion Resistance	2	4	3		3	5	3	2	4	4	30	6.67%
5	Variable Dimensions	5	6	5	7		7	6	6	6	6	54	12.00%
6	Abrasion Resistance	2	4	3	5	3		3	2	4	4	30	6.67%
7	Few Components	5	6	5	7	4	7		7	7	7	55	12.22%
8	Hermetic	4	7	4	8	4	8	3		7	7	52	11.56%
9	Avoid Vibrations	6	4	3	6	4	6	3	3		4	39	8.67%
10	High Resistance	3	5	4	6	4	6	3	3	6		40	8.89%
	TOTAL											450	100.00%



Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Demanded Quality (a.k.a. "Customer Requirements" or "Whats") / Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")	1 Transmission	2 Head shield shape	3 Buckets	4 Space between buckets	5 Security factor	6 Material	7 Number of components	8 Price
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▼	▼	▲	▲	▲	▼	▼	▼
1	9	12.4	12	Low cost	⊙	⊙				O	O	⊙
2	9	8.9	9	Simple maintenance	⊙						⊙	
3	9	12.0	12	Simple instalation	▲		O	▲			⊙	▲
4	9	6.7	7	Corrosion resistances						⊙		
5	9	12.0	12	Abrasion resistance		O				⊙		
6	3	6.7	7	Variable dimensions		O		O			O	▲
7	9	12.2	12	Few components	⊙	⊙		▲			⊙	⊙
8	9	11.6	12	Hermetic		⊙				▲		
9	9	8.7	9	Avoid vibrations	⊙	O					O	
10	9	8.9	9	High resistance	O				⊙	⊙		⊙
				Target or Limit Value								
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	5	8	5	5	3	2	3	2
				Max Relationship Value in Column	9	9	3	3	9	9	9	9
				Weight / Importance	418.6	408.0	36.0	44.2	80.0	296.9	381.3	320.6
				Relative Weight	21.1	20.5	1.8	2.2	4.0	15.0	19.2	16.1

Figures 3 and 4. Pairwise Comparison matrix and QFD matrix

For each function that the test bench had to perform, the advantages and disadvantages of the different design solutions were evaluated. The key points to study were: Rice storaging and loading, allow geometry variation of the head, torque transmission to the shaft and change chaft RPM's. The solution is shown in figure 5 as a table.

Function	Conceptual solution 1	Conceptual solution 2	Conceptual solution 3
Rice storage and loading	Box with switch	Manual inlet	
Allow head's geometry variation	Adjustable head with rails	Modular head	
Shaft's rpm variation	Variable frequency drive	Gearbox	
Transmit torque to the shaft	Belt	Chain	Gear

Figure 5. Morphological chart

As a consequence of this design method and due to project requirements, 3 design alternatives of this test bench were proposed (see figure 6). With the different solutions suggested to the options:

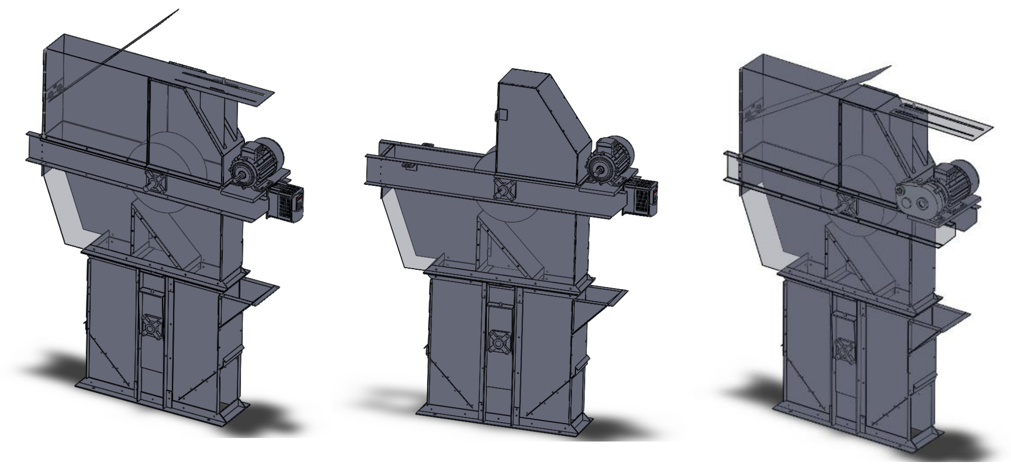
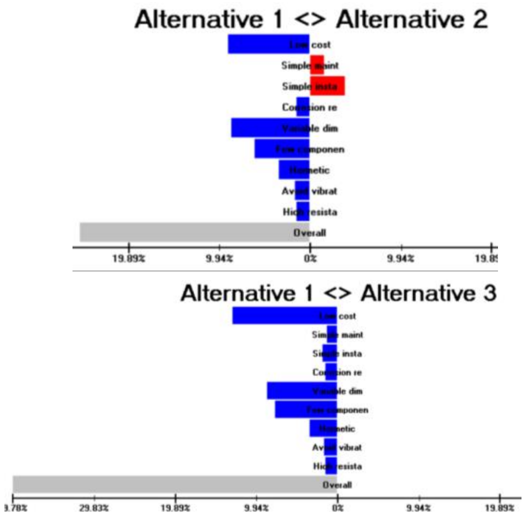


Figure 6. Design alternatives

For the selection of the most appropriate model, an analytical and rational selection tool was used, the Expert Choice® software, which uses a hierarchical analytical process (AHP, Analytical Hierarchy Process). This was consulted with the Superbrix design team. The alternative selected was the first one for a superior general operation.



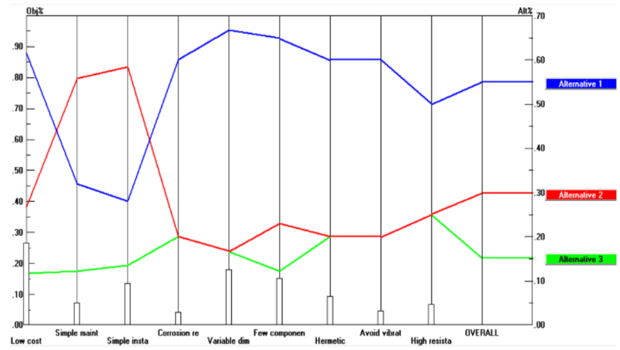
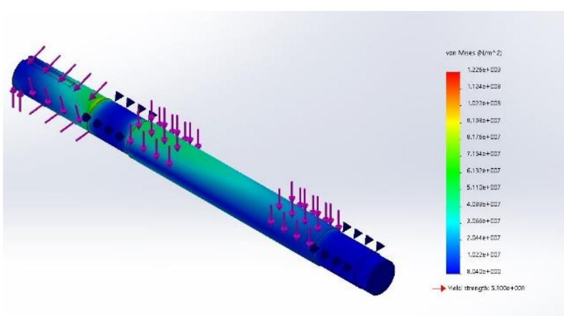


Figure 7 and 8. Alternatives evaluation. Expert choice.

After the selection of the design, all the necessary mechanical calculations for the selection of the components were carried out. Along with the design in CAD, this has been one of the parts with more workload of the project due to its iterative process. Most of the methods have been extracted from specialized manuals, teacher recommendations and client advice. The calculations have been divided into the following sections: Customer conditions, power and torque, selection of bearings, chain selection, pulley drum coupling, shaft design and belt selection. In particular, the design of the shaft has been deepened by teacher requests, using SolidWorks to check the results of the previously made calculations.



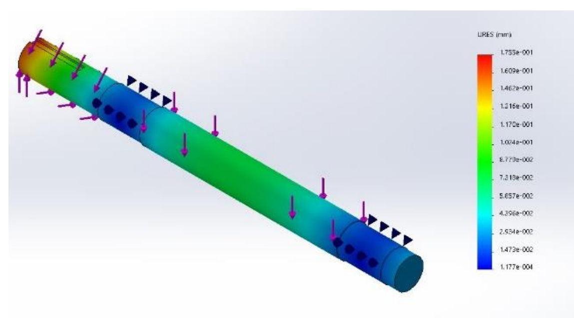


Figure 9 and 10. Statics loads and deformation. Solid Works

3. Testing protocol

All relevant information for testing and analysis of rice damage has been provided. It includes a general description of the properties of the rice and the variables to study, a detailed test procedure and recommendations for data analysis. The ISO 7301 and Codex 198 standards have been consulted for the development of the testing process and the development of the procedures.

Also included are the instructions for carrying out the tests and the necessary laboratory material. Table 10 is a capture of the Excel document created as a statistical data collection sheet for the analysis of the information. In the spreadsheet you can find the grain quality classification factors

Technician		TESTING RECORDS FOR TEST BENCH				
Date						
Grain Type		Sample	Trial 1	Trial 2	Trial 3	Trial Avg.
		A				
Initial Testing	Weight (g)		–	–	–	–
	Large brokens (g)	–				0
	Medium brokens (g)	–				0
	Small brokens (g)	–				0
	Moisture Content (%)		–	–	–	–
	Temperature (°C)		–	–	–	–
	Velocity (Hz)		–	–	–	–
	Head Angle (deg)		–	–	–	–
		B				
Final Testing	Weight (g)		–	–	–	–
	Large brokens (g)	–				0
	Medium brokens (g)	–				0
	Small brokens (g)	–				0

Table 10. Analysis excel sheet screenshot

GRADING FACTORS	GRADE PREMIUM: 1: 2: 3
Head Rice (Min %)	95.00:80.00:65.00:50.00
Large Brokens (Max %)	3.00: 10.00: 10.00:20.00
Broken Other than Large Brokens (Max %)	1.90: 9.75:24.00:29.00
Brewers (Max %)	0.10: 0.25: 0.50: 1.00
Defectives:	
Damaged Kernels (Max %)	- : 0.25:0.50: 2.00
Discolored Kernels (Max %)	0.50: 2.00: 4.00: 8.00
Chalky & Immature Kernels (Max %)	2.00: 5.00: 10.00: 15.00
Contrasting Types (Max %)	3.00: 6.00: 10.00: 18.00
Red Kernels (Max %)	- : 0.25: 0.50: 2.00
Red Streaked Kernels (Max %)	1.00: 3.00: 5.00: 10.00
Foreign Matter (Max%)	- : 0.10: 0.20: 0.50
Paddy (Max. no. per 1000 grams)	1 : 8 :10 :15
Moisture Content (Max %)	14.00: 14.00: 14.00: 14.00

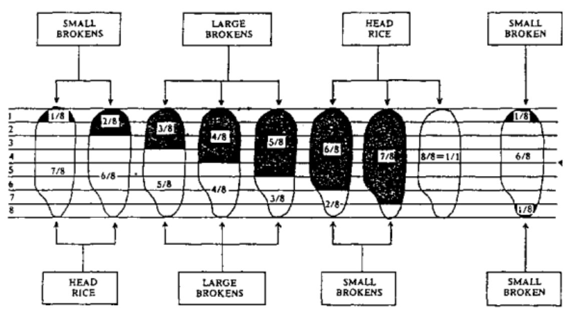


Figure 11 and 12. Grain classification [21]

4. Conclusions and recommendations

From the study it was found that the performance of the equipment and the final quality of the rice depends on the geometrical parameters and operating parameters. The operating velocity should be the first consideration, as well as the diameter of the pulley, these two factors will determine the kinetical energy of the rice, which will be traduced in the impact force. The head geometry is also important, especially if the operating velocities are high, in this case, the head will be the impact surface that will reflects and damage the grain. As a prediction, the parabolical or curved head geometry will perform better due to the parabolic trajectory of the grain. The geometry of the bucket influences the trajectories given that the forces present throughout the launching phenomenon, takes into account the exit angle of the bucket’s outer wall. The space between buckets will influence the capacity and the power required, but probably not the damage caused to the grain.

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Table of Contents

EXECUTIVE SUMMARY

SuperBrix SA is a manufacturing company dedicated to the development of sustainable and innovative solutions for the grain and cereal agribusiness. It plans to make improvements to the design of bucket elevators destined for rice processing. The goal is to make their product competitive in a market that is continuously improving and to guarantee the integrity of the product processed by the equipment to achieve superior customer satisfaction. After an iterative problem-solving process, it has been resolved to design test equipment and complementary testing protocol to evaluate the viability of various designs that aim to improve the performance of the elevators.

SuperBrix recognizes velocity, geometry of the head, spacing between buckets, and the shape of the buckets as the design variables that may impact the performance of a bucket elevator. To provide SuperBrix with a systematic way to measure the effect that each variable has on the rice, it has been designed the testing equipment (test bench) and the accompanying testing protocol. The equipment is designed to allow SuperBrix to change the specified variables and the protocol outlines the exact steps that should be taken to accurately measure the change in grain damage. Supplemented by an extensive research report on rice properties and rice processing, the deliverables will give SuperBrix all the tools necessary to test each variable, analyze the data, make favorable changes to the bucket elevators, and improve the quality and detail of the recommendations they make to clients.

The development of this project began with the review of the state of the art and technique, as well as extensive research on rice processing, rice properties, and existing testing protocol. After a thorough analysis of current mechanical designs in industry and performing related calculations, it has been produced three separate alternatives for the mechanical design of the test bench. A final selection was made following an objective comparison of the designs. The testing protocol for assessing rice quality was defined based on current industry standards and international codes found in our research and on information provided by industry professionals. Thus, the protocol meets or exceeds existing standards and allows SuperBrix to collect and incorporate highly accurate testing data in their product recommendations to clients.

RESUMEN EJECUTIVO

SuperBrix SA es una empresa dedicada a la fabricación de maquinaria para la industria agroalimentaria. Planea hacer mejoras en el diseño de sus elevadores de cangilones, destinados al procesamiento de arroz. El objetivo es hacer que sus productos sean competitivos en un mercado que mejora continuamente y lograr una satisfacción superior del cliente. Después de un proceso iterativo de resolución de problemas, se ha resuelto diseñar un banco y un protocolo de pruebas para evaluar las variables que apuntan a mejorar el rendimiento de los elevadores de cangilones.

SuperBrix reconoce la velocidad, la geometría del cabezal, el espaciado entre cubos y la forma de los cubos como las variables de diseño que pueden afectar el rendimiento de un elevador de cangilones. Para proporcionar a SuperBrix una forma sistemática de medir el efecto que cada variable tiene sobre el arroz, se ha diseñado un banco y un protocolo de pruebas. El equipo está diseñado para permitir que SuperBrix cambie las variables especificadas y el protocolo describe los pasos exactos que se deben tomar para medir con precisión el cambio en el daño del grano. Este proyecto dará a SuperBrix todas las herramientas necesarias para probar cada variable, analizar los datos y realizar cambios favorables en el actual diseño de sus elevadores de cangilones.

Después de un análisis exhaustivo de los diseños mecánicos actuales en la industria y la realización de cálculos relacionados, se han producido tres alternativas para el diseño del banco de pruebas. Se realizó una selección final siguiendo una comparación objetiva. Además, el protocolo cumple los estándares existentes y permite a SuperBrix recopilar e incorporar datos de pruebas de alta precisión en sus recomendaciones de productos a los clientes.

1. INTRODUCTION

Following only corn, rice is the world's second most important cereal. Close to 482 million metric tons of husked rice were produced in the last harvesting year worldwide. The Colombian company SuperBrix designs, builds, and exports equipment destined for agroindustry in milling and rice industrial processes. With a rapidly evolving industrial sector, standards and competitiveness force companies like SuperBrix to always be a step ahead of competitors.

Rice must go through various processes including cleaning, classification, milling, drying, storage, transport, and elevation. Throughout processing, many bucket elevators are utilized to elevate the product from one stage to the next. Bucket elevators are crucial equipment for rice processing and a grain of rice can pass through a dozen of them during its lifetime. It is important to note that rice does not maintain the same properties during all stages of processing. However, current bucket elevators are designed depending only on the capacity, not the fragility of the grain. This can damage the grain by treating it too aggressively in the most fragile stages. It can also decrease efficiency by oversizing equipment when the grain is more resistant and could afford a more aggressive treatment without affecting its quality.

SuperBrix has expressed concerns about the relationship between the elevated product's quality and the operating variables of their elevators. They believe that variables such as velocity of the buckets and the geometry of the head may have an impact on the proportion of damaged rice. The integrity of the rice is a determining factor of the selling price, so it is vital to reduce damage while maintaining processing capacity. Also, increasing capacity of the elevators and having a deeper understanding about the main variables can make them be one step ahead of their competitors.

1.1 PROBLEM STATEMENT

The purpose of this project is to improve SuperBrix bucket elevators, adapt them to new industry standards, and make them competitive within the market of rice processing. The client is specifically interested in how they can increase the conveying capacity without increasing the damage done to the rice during processing. There are four variables that impact conveying capacity and rice damage: geometry of the head, shape of the buckets, spacing between buckets, and velocity.

1.2 OBJECTIVES

To identify the optimal conditions of geometry and operation to maximize production while minimizing damage, the project objectives have been defined as follows:

- Design a test bench to test the main variables that affect the bucket elevator efficiency. These variables include: velocity of the buckets, space between the buckets, size and shape of the buckets, and the geometry of the head.
- Detect the possible problems and elaborate hypothesis. Especially for the bucket type and the shape of the head.
- Design detailed testing protocol to accurately measure the damage of the rice and outline how to compare it with industry standards. It should be a quick and easy process which considers all important parameters and produces accurate results.
- Provide SuperBrix with information about rice properties and mechanical resistance during each stage of rice processing so they can advise clients on which elevator is most suitable in any given situation.

1.3 SCOPE

SuperBrix will be provided with the mechanical design for a test bench as well as detailed testing protocol and compiled research on rice properties and processing. SuperBrix will be responsible for constructing the test bench and for performing the experiments, as they have the machinery, expertise, and funds. The construction of a prototype is out of the scope of this project. Upon completion of testing, SuperBrix will be able to optimize their bucket elevators and provide better recommendations to their clients.

2. METHODOLOGY

2.1 GENERAL METHODOLOGY

To achieve these objectives, all parts of the problem were addressed to give SuperBrix the tools necessary to test and improve their products.

First, research of previous studies and experiments was conducted pertaining to the current design and function of bucket elevators. With this information, it was performed basic physical and mechanical calculations on theoretical performance, especially regarding the geometry of the head. After completing these calculations, the test bench was designed conceptually as sketches and redesigned in SolidWorks, a 3D CAD design software, and approved by the client. Additionally, with the help of the client, a material list and patent revision were completed.

Following the design of the test bench, the accompanying testing protocol was developed. It was performed a detailed analysis of the rice processing industry, rice properties, and rice sampling technique. The research included interviews with professionals in the rice processing field and consultation from department professors. The testing protocol was designed to be lean, fast, and accurate. After compiling the findings, A comprehensive report and presentation have been delivered to SuperBrix which will add value to their products and client recommendations.

Upon completion of the objectives, the parts were integrated into a complete document including blueprints, CAD files, and annexes. The document was organized to be easily understandable by the SuperBrix design team and the operators.

2.2 METHODOLOGY DIAGRAM

Figure 2.2.1 shows the methodology of design used to achieve the objectives of the project.

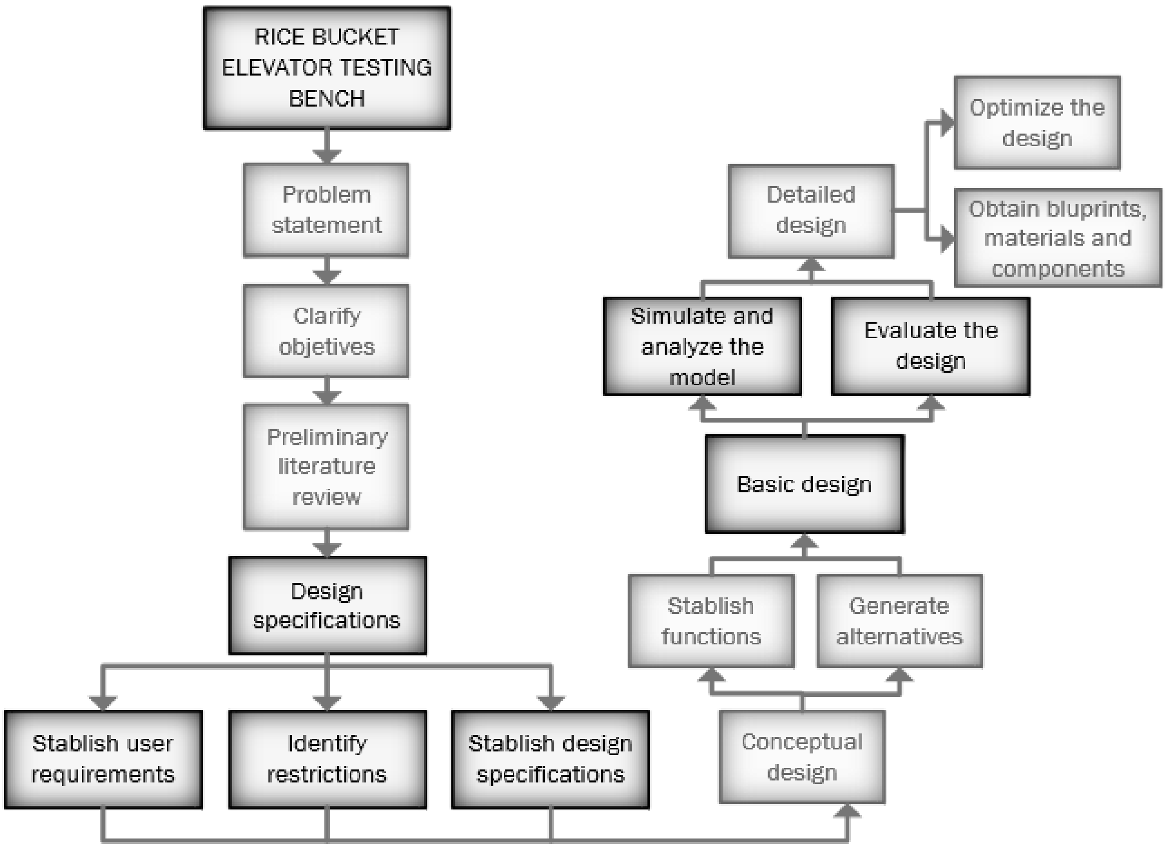

Figure 2.2.1. Methodology of design.

2.3 GANTT CHART

Figure 2.3.1 shows the Gantt Chart outlining the tasks and the estimated timeframe for each.

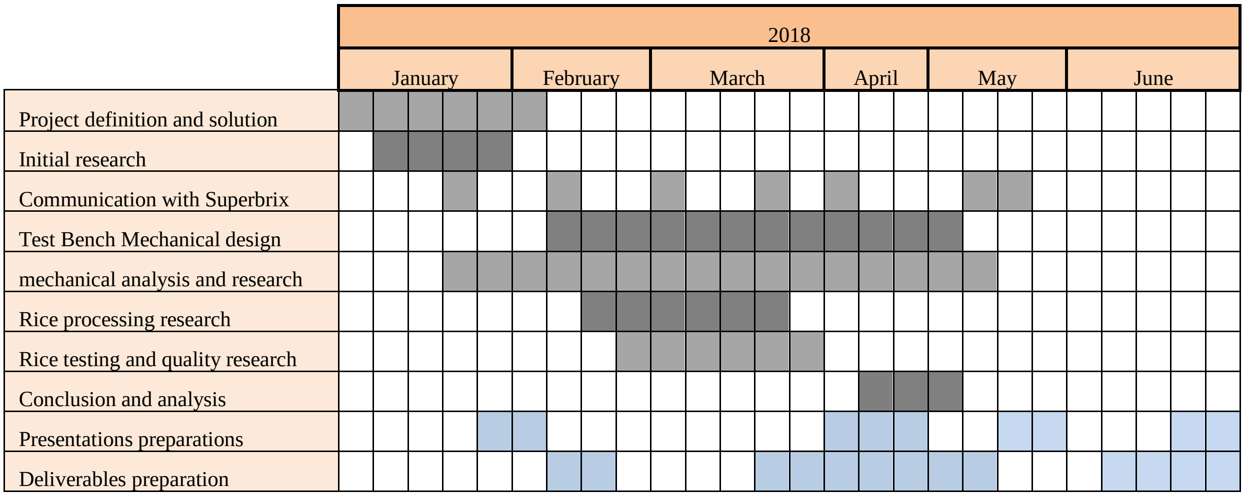

Figure 2.3.1, Project Gantt Chart

2.4 RESOURCES

To complete the outlined objectives, the teams will employ several resources. These include:

1. Solid Works - used to design the test bench and create the blueprints for delivery to SuperBrix.
2. The Microsoft Office package (Word, PowerPoint and Excel) for the documents, presentations, tables, and calculations.
3. Interviews with professionals of the rice industry
4. Articles, books, and papers about bucket elevator design
5. Expert Choice®, a software based on multi-criteria decision making- implements the Analytic Hierarchy Process (AHP) for the evaluation and selection of the best alternative

2.5 DELIVERABLES

The deliverables for this project include the following:

- Final project report
- Mechanical design of test bench including CAD drawings and blueprints
- Testing protocol
  - Rice properties information
  - Rice processing information
  - Existing testing standards

3. STATE OF THE ART

3.1 STATE OF THE ART

The transport of bulk material using mechanisms such as conveyor belts dates from 1795. Due to technological limitations, the materials were transported over relatively short distances. These primitive conveyor systems were simple mechanisms consisting of a leather, canvas or rubber belt traveling over a flat or troughed wooden bed. The effectiveness of these early models was not high, but they were the first step. Over time, engineers improved upon them because there were clearly preferable methods for moving large volumes of materials through space. It is also worth mentioning that they were powered manually, using hand cranks and arrangements of pulleys [2].

Figure 3.1.1. Earlier belt conveyor [3].

The next step in the evolution of this type of material transport was to marry it with an existing technology; the steam engine. This was the first major improvement, making it possible to handle much larger quantities at increased speed. The first documented use of a steam engine powered conveyor belt was by the British Navy in 1804. [4].

Another prime example of the evolution of conveyors is the Colonial Dock installation of the H.C Frick Company in the 1920's. With underground installation and capability to handle coal over five miles, it showed what belt conveyors could achieve. This specific conveyor had a belt consisting of multiple piles of cotton duck and natural rubber covers [2].

Materials for belting had to evolve thanks to World War II; it provoked a shortage of natural components that, until that moment, were the main option. The rubber industry was then forced to create a replacement for them; synthetic materials, which are still used today [2]. This opened the door to even more possibilities. The great variety of polymers and fabrics provided new ways of meeting more exigent design requirements.

It is also necessary to remark how conveyors affected the industry. Henry Ford implemented them in the first ever assembly lines, thus saving time moving cars through the stages of production. This method greatly reduced the time of manufacturing an automobile [5]. This demonstrates how integrating material handling operations can maximize the productivity of a plant.

Figure 3.1.2. Ford's assembly line [6].

Conveyor technology has developed over time to adapt to changing needs. Nowadays "conveyors" fall into the category of "continuous machines" of the most general category, "conveying machines". In this category, we can also find pneumatic handling devices and hydraulic handling devices. Looking more into conveyors, we can classify them into 2 main types; with pulling members and without pulling members. Most common in the pulling member category are the belt conveyors and bucket elevators, while screw conveyors do not use a pulling member. From now on, bucket elevators will be emphasized.

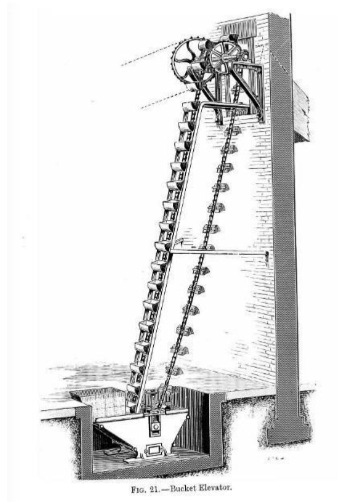

Figure 3.1.3. Old Bucket elevator model [25]

For vertical lifts, buckets elevators are the simplest and most used units. Their utility comes from their wide range of capacities and operation possibilities; they can operate in enclosed or open environments, depending on the material being handled. In today's industry, the trend is highly standardized units, but there may be cases where specialized designs may be necessary. Differences can be found in the geometry (casing thickness), the buckets, the belt, and the drive equipment [7].

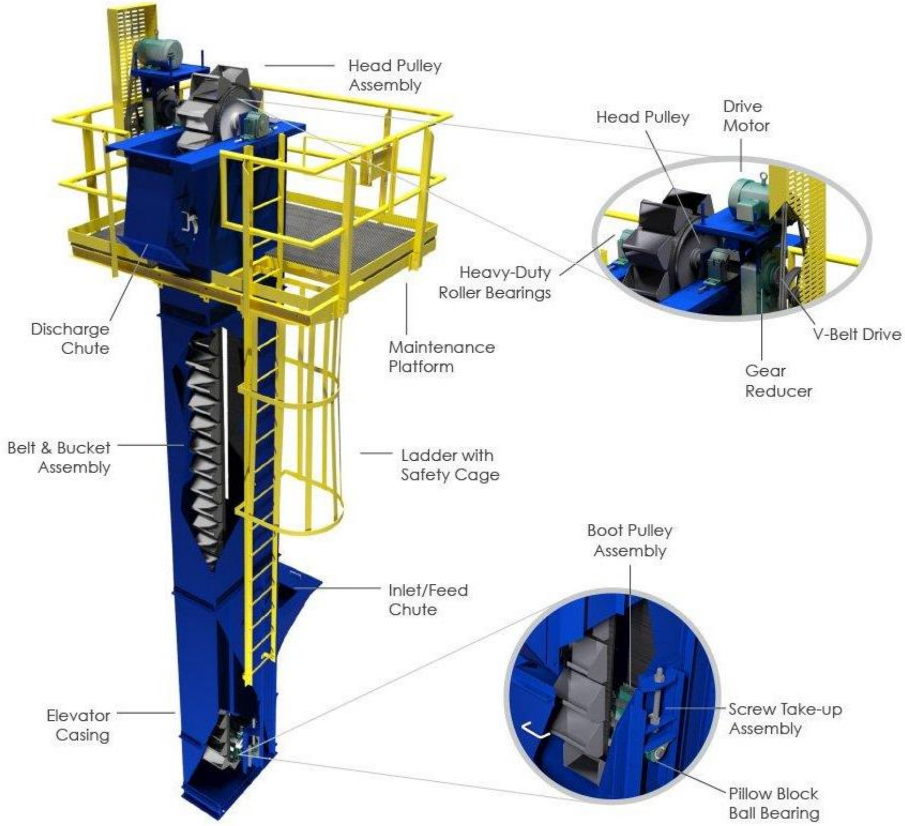

Figure 3.1.4. Bucket elevator components [8].

There is also a trend of reducing the space occupied by these material handling units by making them as compact as possible. This implies that to maintain the same levels of productivity, some parameters should be changed. For example, the working speed should be increased. With the actual designs, there are limitations concerning the maximum speed of the buckets. Exceeding theses limits causes negative consequences such as damage to the handled material, decreased return of the material, and incremented energetic consumption.

Current research shows evidence that manufacturers may not have considered the material deterioration during transport or the energetic problem. There have been many approaches to these problems, including changing conventional designs based on the physical phenomena that governs the functioning of the elevators and more complex discontinuous deformation analysis of the handled material that would lead to an optimum bucket geometry working under given specific conditions [9].

Rice has been processed since the beginning of time, but the industry standards are now more demanding than ever. The quality and damage of rice have become important variables that directly impact its pricing. Since bucket elevators are included in most of the stages of rice processing, they must evolve and adapt to new industry standards.

3.2 RICE PROCESSING AND MILLING PROCEDURES

3.2.1 Importance and definitions

It is important to understand different rice processing and milling procedures to give an appropriate recommendation about which parameters should be considered in the bucket elevator design. The state of the grain varies between each step as certain properties fluctuate and reduce the grain strength (i.e. presence of the husk and moisture content). When the grain enters the processing and milling facility, it can withstand more impact as the outer husk protects the grain and its high moisture content makes it less brittle. When the husk is removed, and the grain is polished, its strength decreases, making it more prone to damage.

Figure 3.2.1 depicts the general rice milling process (not all processing plants follow the same procedures), which provides a general idea of how the grain is modified throughout. Note the impact that bucket elevators can have on the grain quality throughout the milling process.

The terms "Rough rice", "Brown rice" and "Milled rice" will be mentioned frequently throughout this document. Rough rice, also referred as "Paddy Rice", is the raw rice before processing. The husk or hull is still intact. Brown rice is the rice state after de-husking, with the bran layer that gives it a brown color. Milled rice is often the final rice stage and is white from the bran polishing.

Rice Milling Process Flow Chart

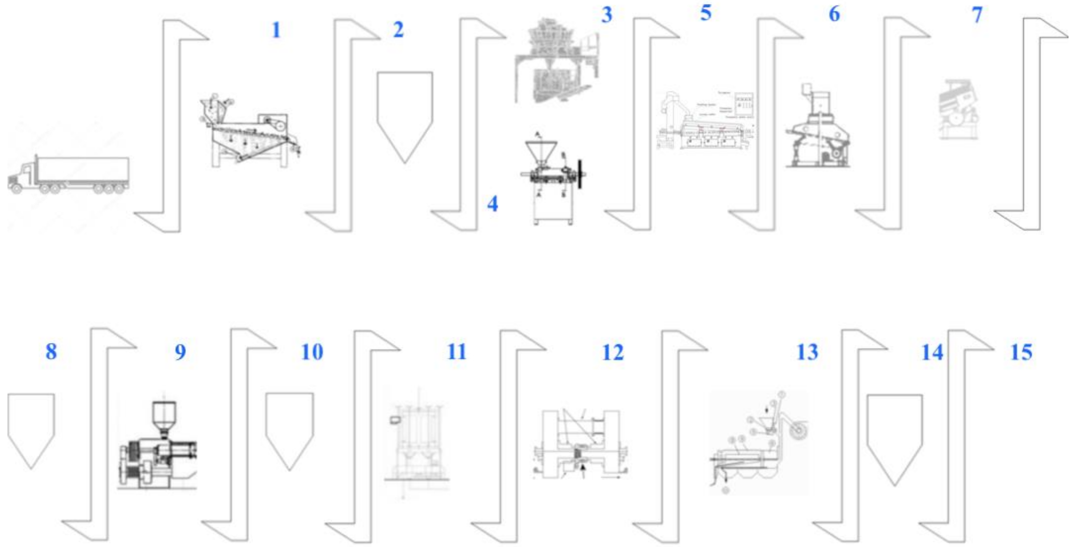

Figure 3.2.1: Rice Milling Process Flow Chart

Paddy input

1. *Pre-cleaning (Grain type: Rough Rice)

2. *Storage (Grain type: Rough rice)

3. Continuous weighing of incoming grain (Grain type: Rough Rice)

4. *Husk removal (Grain type: Rough Rice)

5. *Grain and husk separation (Grain type: Brown and Rough Rice)

6. *Grain and stones separation (Grain type: Grain type: Brown and Rough Rice)

7. *Paddy Collection (Grain type: Grain type: Brown and Rough Rice)

8. *Storage (Grain type: Brown Rice)

9. *Grain polishing (Grain type: White Rice)

10. *Storage tanks (Grain type: White Rice)

11. *Grain shining (Grain type: White Rice)

12. *Grain selection, length (Grain type: White Rice)

13. *Grain selection, breakage (Grain type: White Rice)
14. *Storage (Grain type: Finished Product)
15. Weighing and packing (Grain type: Finished Product)

* Elevator involved

The first stage of the process is "Pre-cleaning". A separating machine is used to remove all foreign materials from the rough rice. This includes rice straw from harvesting, stones, small seeds, and other impurities. The hull of the grain is kept intact. The rough rice is stored in tanks until it is weighed. The "clean" rough rice flow is measured using a continuous weight. In the fourth stage, the rice enters the paddy husker, which removes the hull, and becomes brown rice. The product of this stage is a mixture of brown rice and the removed husks.

The husks are separated from the brown rice in a gravity separator. This machine uses the floating principle to differentiate the specific gravity of hulls and grain. Then, at the de-stoner machine, foreign material is separated and sorted by physical characteristics such as gravity, volumetric weight, the coefficient of friction, and suspension velocity. The output is then fed into the paddy separator, where the mixture of brown and rough (the portion that remained with the husk after the paddy husker) is separated. The brown rice moves to the next step and the rough rice repeats the cycle.

The brown rice is transferred to a whitening machine, where the bran layer of the rice is polished, transforming the grain into white rice or milled rice. This process is followed by the shinning machine, where water is sprayed, and the milled rice is set on a milling roller to clean the rice dust and remove any fungi from the rice surface. The grain then enters a rotary shifter and a length grade, where the it is divided based on the degree of breakage. This is described in future sections.

3.3 PATENT REVISION

Patent	Author	Analysis
Bucket Elevator (US3040873A) June 26, 1962.	William Hobbs, Jr.	This patent is for an elevator that transports grain from a supply point to an elevated discharge point. It is comprised of a rotatable toothed sprocket with each having a notch extending radially inward from the outer edge, a second rotatable sprocket vertically spaced from the first sprocket, an endless chain composed of a plurality of pivotally connected links entrained around said sprockets with said notched teeth engaging said chain between consecutive pivotal connections, at least one bucket having a back wall provided with an elongate channel therein, means connecting said back wall at opposite sides of said channel to opposite sides of a single chain link with said connecting means and said link bridging said channel, all portions of said link and said connecting means being disposed outside of said channel, said channel extending parallel to the path of travel of said chain a distance greater than the length of said single link in the same direction, said channel having width in a direction transverse to the path of travel of said chain greater than the width of said single link in the same transverse direction, whereby when said bucket passes around said first sprocket to pick up grain at said supply point, grain between said sprocket teeth and said chain, said chain and said back wall and said teeth and said back wall may escape through said channel and notch and avoid being crushed by the relative movement of said sprocket, chain and back wall [10].
Bucket grit elevator system. (US5336417A) September 18,1992.	Joseph R. Hannum.	This patent consists of a bucket elevator system for a waste water treatment facility which is made of non-metallic components. Buckets are carried along a bottom surface of a settling tank and then lifted above the waste water level and tilted to dump the collected waste solids onto an external disposal system. The buckets include a plurality of dewatering slots which allow the water to drain from the buckets as they are lifted from the settling tank. Split block

		bearing assemblies are provided for drive shafts of the conveyor [11].
Intersecting bi-directional buckets for a bucket elevator system. (US5526921A) June 18, 1996.	Robert J. Kovalak. Harold E. Patterson. Paul I. Sleppy.	This patent is about a bucket elevator system capable of being driven bi-directionally. The system having a plurality of pivoted buckets supported between two endless chains. Each bucket having a primary guide boss with an upper surface and a guide surface thereon. Guides arranged to contact the upper surface of the primary guide boll to restrain the pivotal movement of the buckets [12].
Bucket elevator conveyors (US5641057A) May 11, 1994.	Derek Carr Chorlton	This bucket conveyor consists of an array of buckets which are pivotally suspended between two chains and run around an endless circuit. The claims are made up of links being connected by pins in elongated holes. This chain can be compressed to make its length less than when it is under tension. The chain is compressed at the loading station to force buckets into direct contact with each other and allow continuous 10 loading. At the discharge station the chain is put under tension to space the buckets and allow them to be rotated though 360° to empty out their contents. Guides are positioned at the areas where the chain is under compression to stop buckling from occurring. The system is driven by a motor and sprockets which also control the compression or tension of the chain [13].
Bucket elevator (US6220425B1) April 24, 2001	Dorcel Warren Knapp	This system consists of a boot-driven bucket elevator apparatus for bulk material handling that is provided with a boot pulley drive and take-up with effects rotation of the apparatus co-operating bucket endless belt, which is platform lever-mounted, and which automatically effects proper tensioning and centering of the apparatus endless belt by the gravitational weight of the drive and take-up [14].

Table 3.3.1. List of existing patents

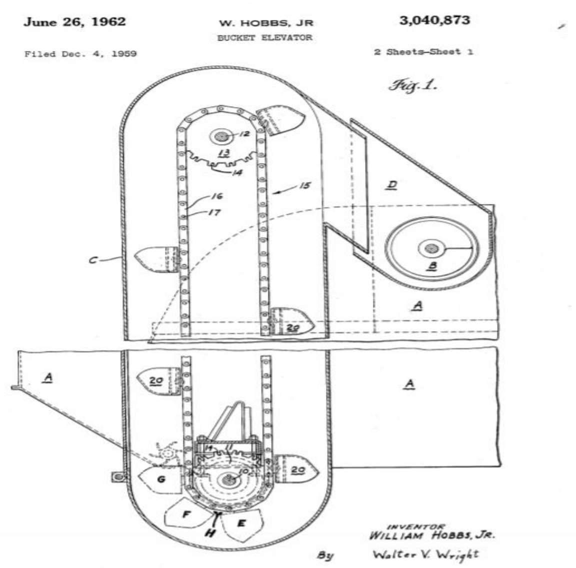

Figure 3.3.2. Bucket elevator (US3040873A) [10].

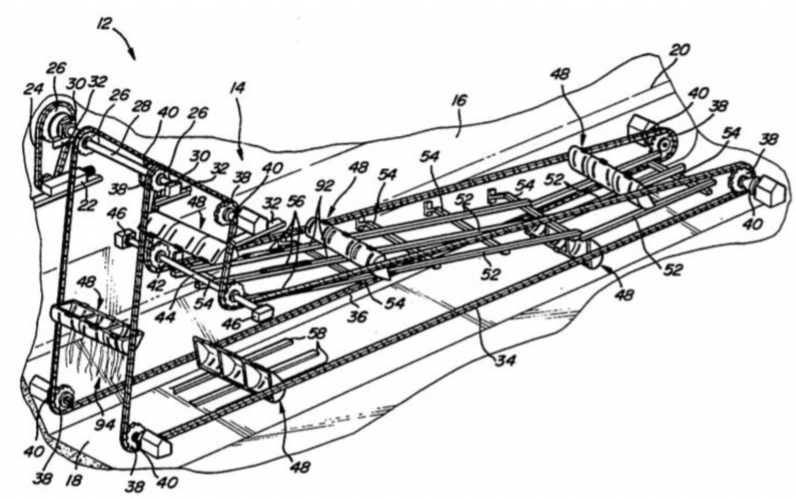

Figure 3.3.3. Bucket grit elevator system (US5336417A) [11].

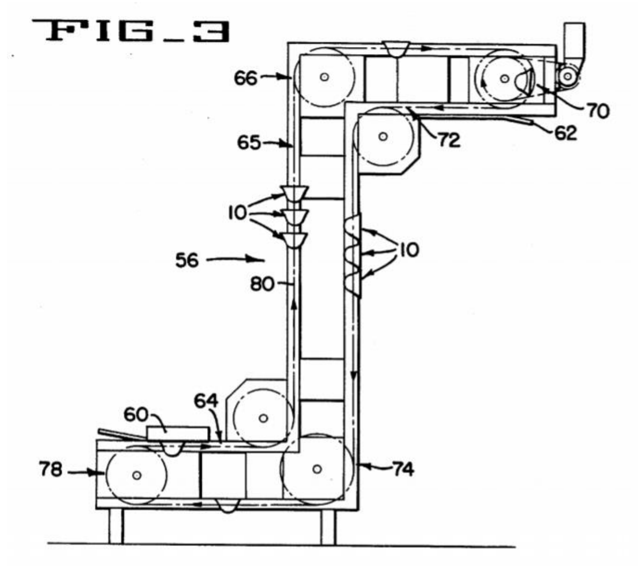

Figure 3.3.4. Intersecting bi-directional buckets for a bucket elevator system (US5526921A) [12].

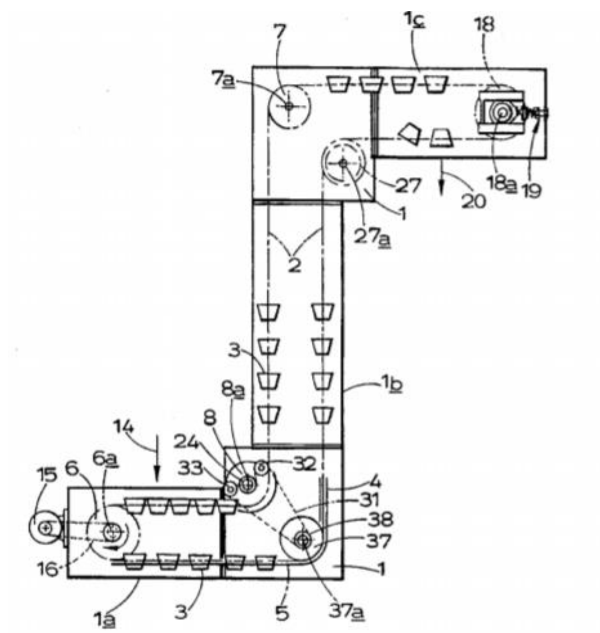

Figure 3.3.5. Bucket elevator conveyors (US5641057A) [13].

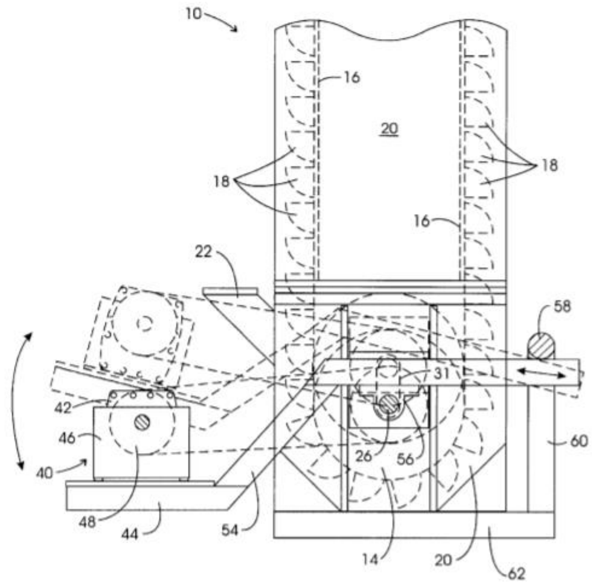

Figure 3.3.6. Bucket elevator (US6220425) [14].

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4. DESIGNING THE TEST BENCH

4.1 DESIGN OBJECTIVES

The system specifications were made along with the design team leader of SuperBrix S.A. This section lists the specifications of the essential aspects of the design, components, functions, and constraints, all in accordance with the expectations of the client. *Figure 4.1.1* is a process flow diagram depicting the complete process and its stages. *Figure 4.1.2* is a more specific schematic of the process.

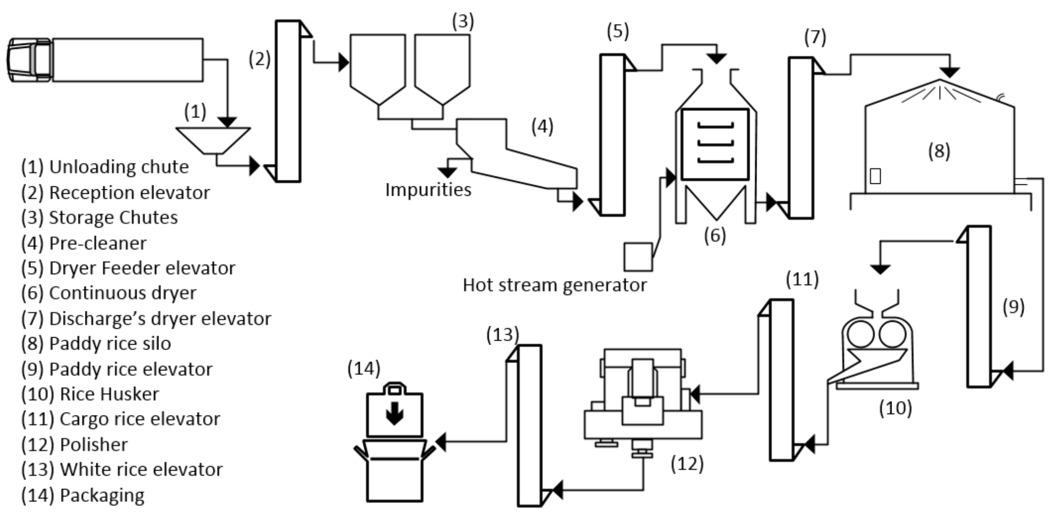


Figure 4.1.1 Process general scheme.

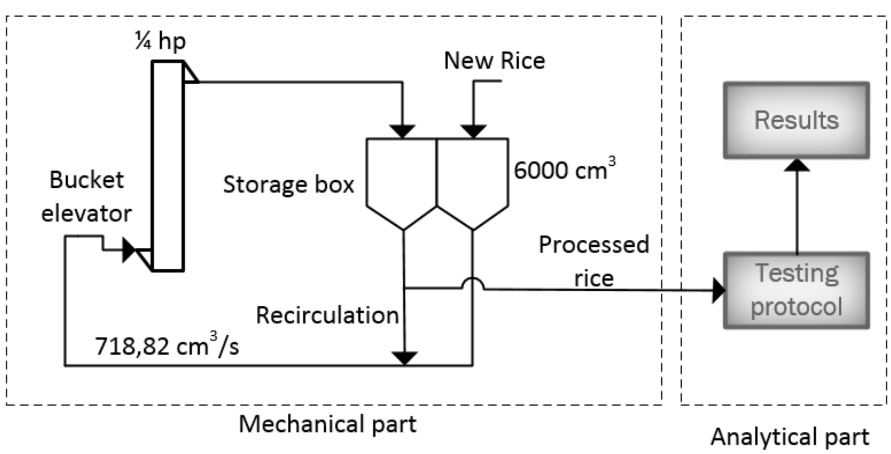


Figure 4.1.2. Process specific scheme.

4.2 PAIRWISE COMPARISON

A pairwise comparison chart aids in the prioritization of design objectives. For each parameter, a number from 1 (least important) to 10 (most important) is assigned. The pairwise comparison is outlined in *Table 4.2.1* below.

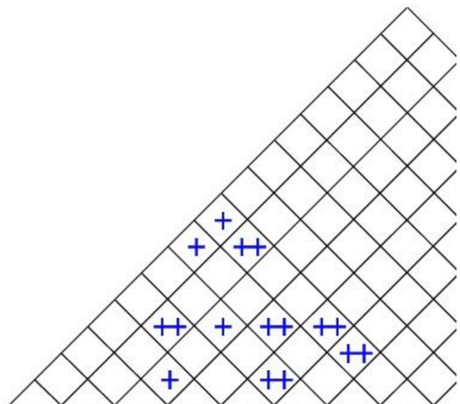
Pairwise Comparison		1	2	3	4	5	6	7	8	9	10	Sum	Relative Weight
		Low Cost	**Simple Maintenance**	**Simple Installation**	**Corrosion Resistance**	**Variable Dimensions**	**Abrasion Resistance**	**Few Components**	**Hermetic**	**Avoid Vibrations**	**High Resistance**		
1	**Low Cost**		7	6	8	5	8	5	6	4	7	56	12.44%
2	**Simple Maintenance**	3		3	6	4	6	4	3	6	5	40	8.89%
3	**Simple Installation**	4	7		7	5	7	5	6	7	6	54	12.00%
4	**Corrosion Resistance**	2	4	3		3	5	3	2	4	4	30	6.67%
5	**Variable Dimensions**	5	6	5	7		7	6	6	6	6	54	12.00%
6	**Abrasion Resistance**	2	4	3	5	3		3	2	4	4	30	6.67%
7	**Few Components**	5	6	5	7	4	7		7	7	7	55	12.22%
8	**Hermetic**	4	7	4	8	4	8	3		7	7	52	11.56%
9	**Avoid Vibrations**	6	4	3	6	4	6	3	3		4	39	8.67%
10	**High Resistance**	3	5	4	6	4	6	3	3	6		40	8.89%
TOTAL												**450**	**100.00%**

Table 4.2.1. Pairwise Comparison.

4.3 QUALITY FUNCTION DEPLOYMENT

The QFD matrix is a useful tool in the design process. *Table 4.5.1* uses the same variables as the pairwise comparison to determine the most important engineering decision criteria. There is no much difference between the parameters, but the most important criteria seem to be the transmission and the head shield shape, without forgetting the number of components and the price.

Legend		
⊙	Strong Relationship	9
O	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
—	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
x	Objective Is To Hit Target	



Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Demanded Quality (a.k.a. "Customer Requirements" or "Whats") / Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")	Transmission	Head shield shape	Buckets	Space between buckets	Security factor	Material	Number of components	Price
				Column #	1	2	3	4	5	6	7	8
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▼	▼	▲	▲	▲	▼	▼	▼
1	9	12.4	12	Low cost	⊙	⊙				O	O	⊙
2	9	8.9	9	Simple maintenance	⊙						⊙	
3	9	12.0	12	Simple instalation	▲		O	▲			⊙	▲
4	9	6.7	7	Corrosion resistances						⊙		
5	9	12.0	12	Abrasion resistance		O				⊙		
6	3	6.7	7	Variable dimensions		O		O			O	▲
7	9	12.2	12	Few components	⊙	⊙		▲			⊙	⊙
8	9	11.6	12	Hermetic		⊙				▲		
9	9	8.7	9	Avoid vibrations	⊙	O					O	
10	9	8.9	9	High resistance	O				⊙	⊙		⊙
				Target or Limit Value								
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	5	8	5	5	3	2	3	2
				Max Relationship Value in Column	9	9	3	3	9	9	9	9
				Weight / Importance	418.6	408.0	36.0	44.2	80.0	296.9	381.3	320.6
				Relative Weight	21.1	20.5	1.8	2.2	4.0	15.0	19.2	16.1

Table 4.3.1. House of quality.

4.4 CONCEPTUAL DESIGN

The objective of this section is to understand the process dynamics, generate solution alternatives, and evaluate them according to the specifications definition.

The black box approach, in *figure 4.6.1*, includes the inputs and outputs of the process. The function-means tree, in *figure 4.6.2*, lists the primary and secondary functions. Lastly, the transparent box diagram, in *figure 4.6.3*, shows the functions and their relationships with the inputs.

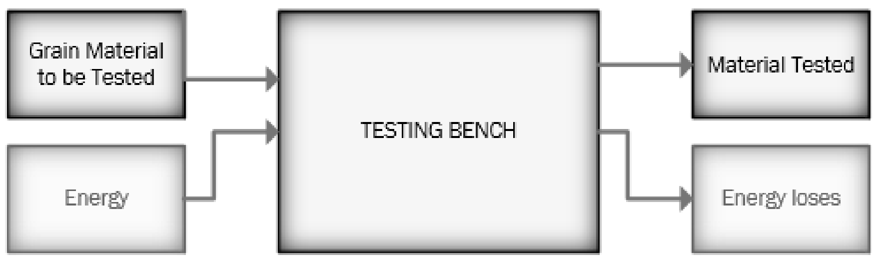


Figure 4.4.1. Black box.

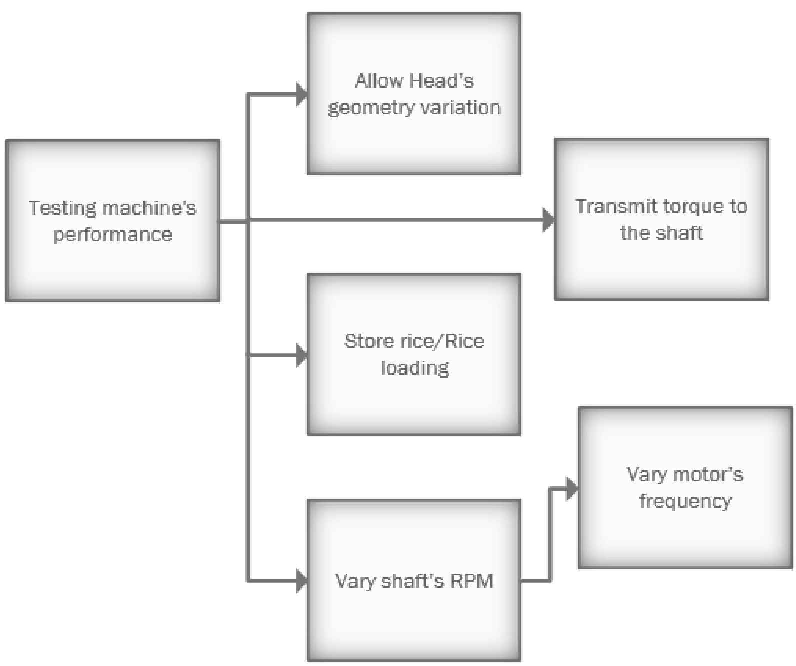


Figure 4.4.2. Function-means tree.

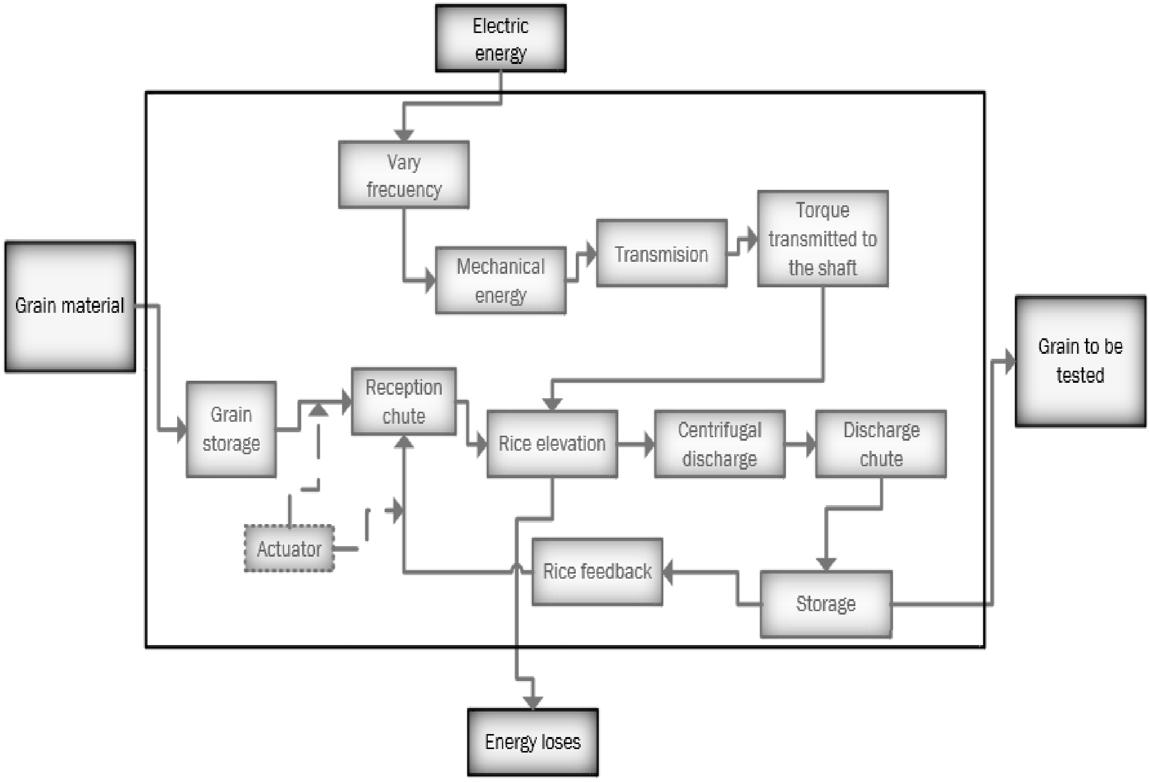


Figure 4.4.3. Transparent box.

4.5 CONCEPTUAL SOLUTIONS GENERATION

This section includes preliminary information for each function and presents advantages and disadvantages.

4.5.1 Rice storage and loading

Box with switch: This system includes two boxes sharing a common line to the inlet chute of the elevator. Each box has a switch that allows it to be opened after the elevator reaches a stable rotational speed. Un-tested rice is placed in the first box. The second box is connected through a pipeline to the discharge chute of the elevator and, to save material, is used only when feedback is desired. The advantages and disadvantages are listed in *table 4.5.1.1*.

Advantages	Disadvantages
• Semi/complete automatized operation. • Little maintenance. • Low cost. • Easy installation.	• It occupies larger space.

Table 4.5.1.1 Advantages and disadvantages of Box with switch

Manual inlet: An operator is present at the inlet chute of the elevator to feed rice through the chute when the machine reaches a stable rotational speed. The operator can feed the elevator with un-tested rice or feedback rice. *Table 4.7.1.2* outlines the advantages and disadvantages of this mechanism.

Advantages	Disadvantages
• It does not require maintenance. • It does not require installation.	• Possible rice losses to human mistakes. • Non homogenous elevator loading.

Table 4.5.1.2 Advantages and disadvantages of Manual Inlet

4.5.2 To allow geometry variation of the head

Modular head: Modular elements are transportable, removable, and interchangeable. A standard base for the head allows testing of different head shapes to find the optimal configuration. *Table 4.5.2.1* outlines advantages and disadvantages of the modular head.

Advantages	Disadvantages
• There's a chance to create any head geometry that is desired to be tested and check its efficacy. • Easy installation and disassembling. • Little maintenance.	• A different head must be created to test any desired geometry. • Higher costs. • More time required between tests.

Table 4.5.2.1 Advantages and disadvantages of Modular head

Adjustable head with rails: An adjustable head with rails allows changes in the angle of inclination of the area where grain impacts after discharge; an optimal angle can be found with this configuration. *Table 4.5.2.2* outlines advantages and disadvantages of the adjustable head.

Advantages	Disadvantages
• Great changes in geometry with a simple adjustment. • Allows to find a relation between the angle of inclination and the damage of the grain. • Just one head needs to be made. • Lower total cost.	• Higher initial cost. • More expensive maintenance. • It only allows straight positions for the sheet.

Table 4.5.2.2 Advantages and disadvantages of Adjustable head with rails

4.5.3 For Torque transmission to the shaft

Chain: This transmission element acts between two parallel shafts with sprockets. Depending on its configuration, it can be used in conveyor systems or in lifting systems. It is analyzed in detail in *table 4.5.3.1*.

Advantages	Disadvantages
• High power transmission efficiency, close to 98%. • Distance between shafts can be changed because the chain can be elongated or trimmed. • Great power can be transmitted using many chains.	• It consists of many elements. • Elevated initial cost. • Requires a careful installation to avoid over stressing. • Frequent lubrication is required.

Table 4.5.3.1 Advantages and disadvantages of Adjustable head with rails

Belt: Transmission system between shafts which uses multiple pulleys and a belt. The belt is made of a flexible material and mechanically joins the two shafts, transmitting power from one to another. This system works due to the friction between the belt and the pulleys. Its advantages and disadvantages are weighed in *table 4.5.3.2.*

Advantages	Disadvantages
• Low cost. • The shafts don't need to be parallel. • It can absorb vibrations. • There is protection in case of overload. • It's silent. • Does not need lubrication. • Easy coupling and disengaging. • Greater speeds in comparison to the chain.	• Restricted range of operation temperature; between -35 °C and 85 °C. • Constant maintenance is required. • Greater power losses. • Fatigue on the shaft can happen. • Higher diameter of pulleys

Table 4.5.3.2 Advantages and disadvantages of Adjustable head with rails

Gear: Rigid power transmission system which connects parallel or coplanar gears. It has great resistance because gears are usually made of steel or bronze. The advantages and disadvantages are weighed in *table 4.5.3.3.*

Advantages	Disadvantages
• Great power transmitting capacity. • Overall easy installation. • No possibility of slipping. • Compact. • Uniform radial speed. • Highly reliable.	• Limited distance between shafts. • High noise levels when working at high speeds. • Fatigue is one of the main mechanism of failure.

Table 4.5.3.3 Advantages and disadvantages of Adjustable head with rails

4.5.4 To change shaft's RPM

Variable frequency drive: Allows changes in velocity and torque of an AC motor by changing voltage and frequency inputs. *Table 4.5.4.1* outlines the advantages and disadvantages of the variable frequency drive.

Advantages	Disadvantages
• Test different rotational speed changing input frequency of the motor. • Cheap maintenance. • Possibility to create control loops. • Higher life cycle of the motor.	• Impossible to fix damage *in-situ*. • Expensive. • Can generate interference in the electrical grid.

Table 4.5.4.1 Advantages and disadvantages of Adjustable head with rails

Gearbox: Rigid transmission system using gears with varying diameters, allowing changes in rotational speed by changing the gear used. *Table 4.5.4.2* outlines the advantages and disadvantages of the variable frequency drive.

Advantages	Disadvantages
• No undesired velocity changes.	• Needs the use of a clutch system and stick shift to change the speed; if not used a clutch, the motor need to be stopped to be able to move the stick shift. • Produces noise. • High maintenance and lubrication needed. • Higher initial cost.

Table 4.5.4.2 Advantages and disadvantages of Adjustable head with rails

4.6 MORPHOLOGICAL CHART

The conceptual solutions for each function are shown in *table 4.8.1*. Three final alternatives are selected with different color arrow paths.

Function	Conceptual solution 1	Conceptual solution 2	Conceptual solution 3
Rice storage and loading	Box with switch	Manual inlet	
Allow head's geometry variation	Adjustable head with rails	Modular head	
Shaft's rpm variation	Variable frequency drive	Gearbox	
Transmit torque to the shaft	Belt	Chain	Gear

Table 4.6.1. Morphological chart.

Preliminary solution alternatives are:

1st alternative: A system with a box for storage and loading, adjustable head with rails, a variable frequency drive and a belt to transmit power.

2nd alternative: A system with a box for storage and loading, modular head, a variable frequency drive, and a chain to transmit power.

3rd alternative: A system with a manual inlet, modular head, a gear box to change speed, and a belt to transmit power.

4.7 SOLUTION ALTERNATIVES DESCRIPTION

4.7.1 First Alternative

This alternative, shown in *figure 4.7.1.1*, replaces the static head with an adjustable head to change the slope of the inclined sheet. The speed of the motor is controlled by a variable frequency drive to find the optimal trajectory of the rice jet. The power is transmitted by a belt from the motor to the shaft and the rice is placed in a box before entering the elevator. The bill of materials and schedule are shown in *table 4.7.1.2* and *figure 4.7.1.3* respectively.

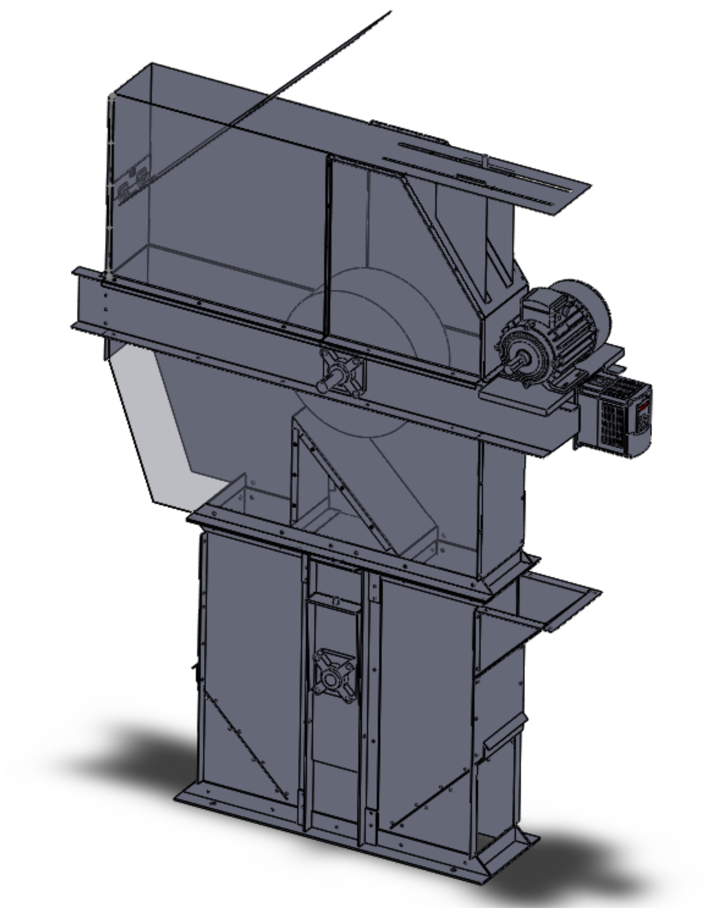


Figure 4.7.1.1. Alternative 1 CAD.

COMPONENT	DESCRIPTION	QUANTITY
Variable frequency drive	Kinco CV20-2S-0004G VFD	1
Belt pulleys	Congress Fixed Bore V-Belt Pulleys	4
Transmission belt	Dayton 4L/A V-Belt	2
Buckets	Tapco High Density Polyethylene Elevator Buckets 5 x 4	10
Pulley bearings	Tritan 4-Bolt Flange Bearings	4
Shaft bearings	Dayton Pillow Block Bearings	4

Table 4.7.1.2. BOM of alternative 1.

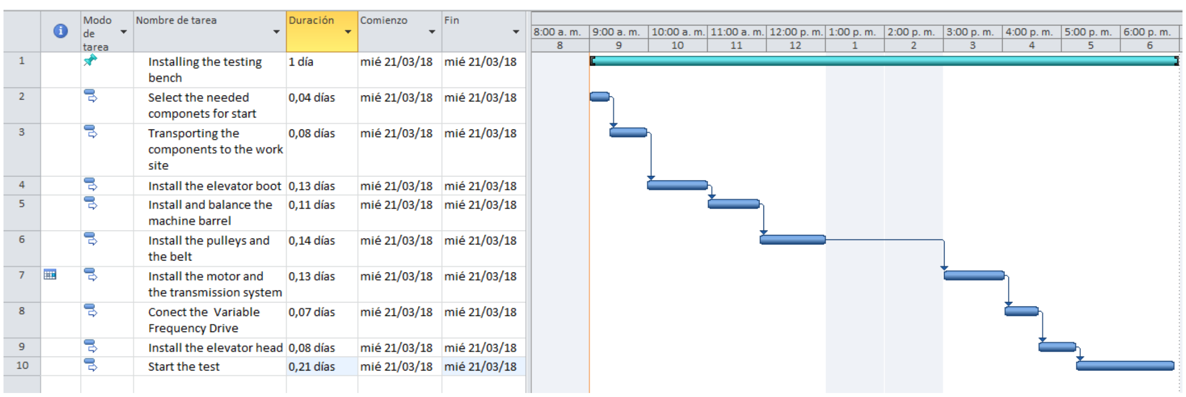


Figure 4.7.1.3. Schedule of alternative 1.

4.7.2 Second alternative

This alternative, illustrated in *figure 4.7.2.1*, partially conserves the static head; the elevator has multiple static heads that can be interchanged, each with a different geometry. Combined with the variable frequency drive, this allows testing for the optimal head configuration and trajectory of the rice jet. Power is transmitted by a chain connecting sprockets in the pulley shaft and motor shaft. The rice is placed in a box. The bill of materials and schedule are shown in *table 4.7.2.2* and *figure 4.7.2.3* respectively.

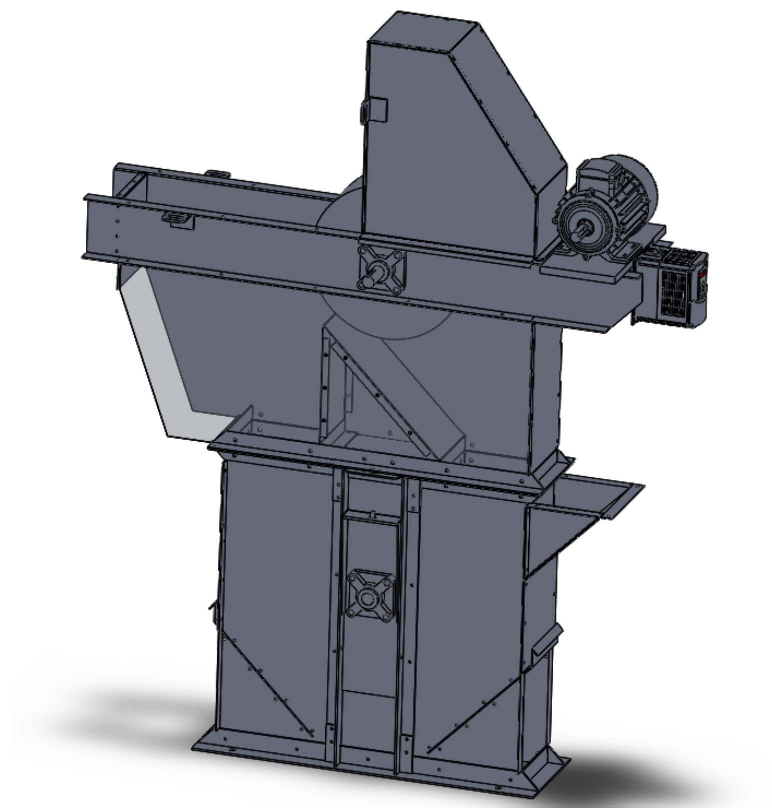


Figure 4.7.2.1 Alternative 2 CAD.

COMPONENT	DESCRIPTION	QUANTITY
Variable frequency drive	Kinco CV20-2S-0004G VFD	1
Sprockets	Tritan Industry Chain Sprockets	4
Transmission chain	Dayton Heavy Riveted Roller Chain	2
Buckets	Tapco High Density Polyethylene Elevator Buckets 5 x 4	10
Pulley bearings	Tritan 4-Bolt Flange Bearings	4
Shaft bearings	Dayton Pillow Block Bearings	4

Table 4.7.2.2 BOM of alternative 2.

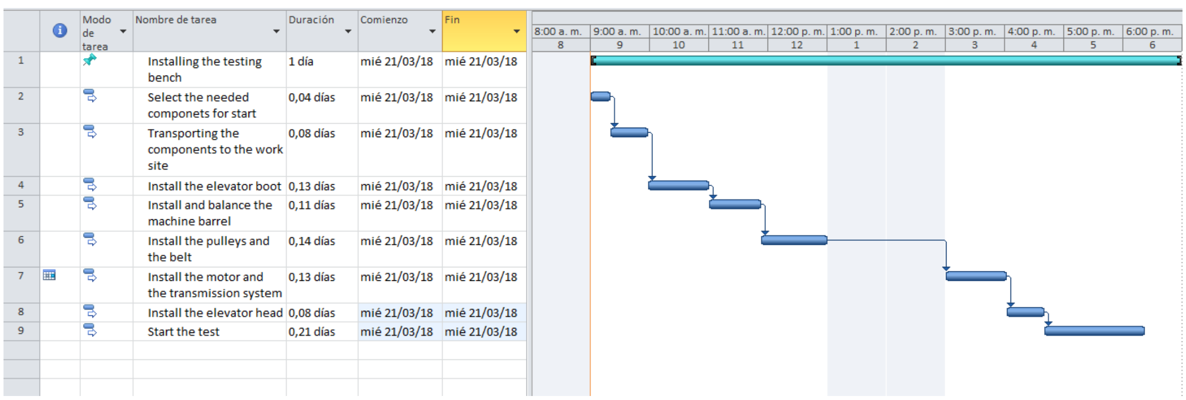


Figure 4.7.2.3. Schedule of alternative 2.

4.7.3 Third Alternative

This alternative, shown in *figure 4.7.3.1,* includes interchangeable static heads and allows velocity adjustment via a gearbox. The gearbox has a stick shift and the motor must be stopped to change the speed. In this alternative, the elevator is loaded by an operator who must wait until the motor reaches the stable velocity. The power from the output of the gearbox to the shaft is transmitted by a belt. The bill of materials and schedule are shown in *table 4.7.3.2* and *figure 4.7.3.3* respectively.

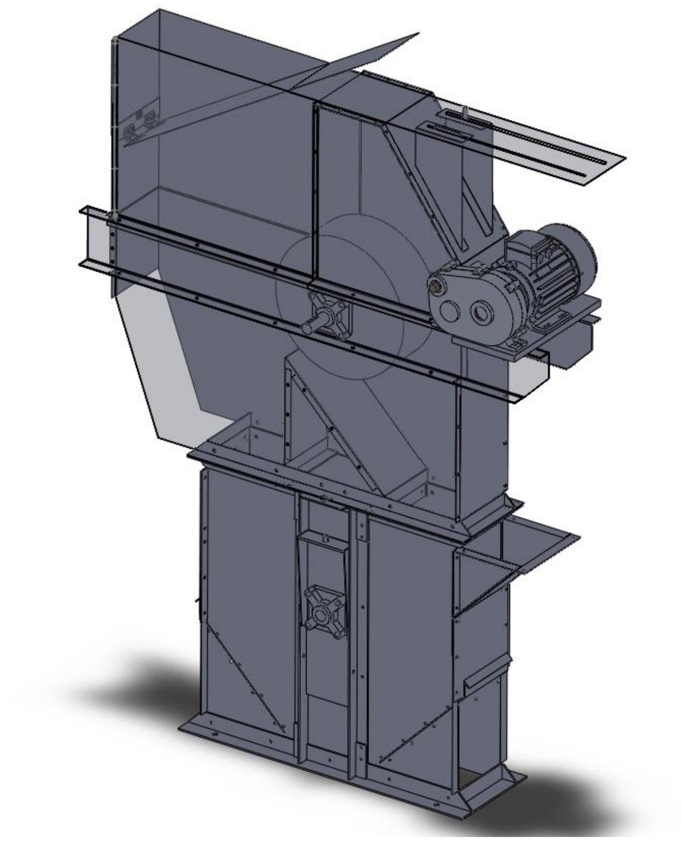
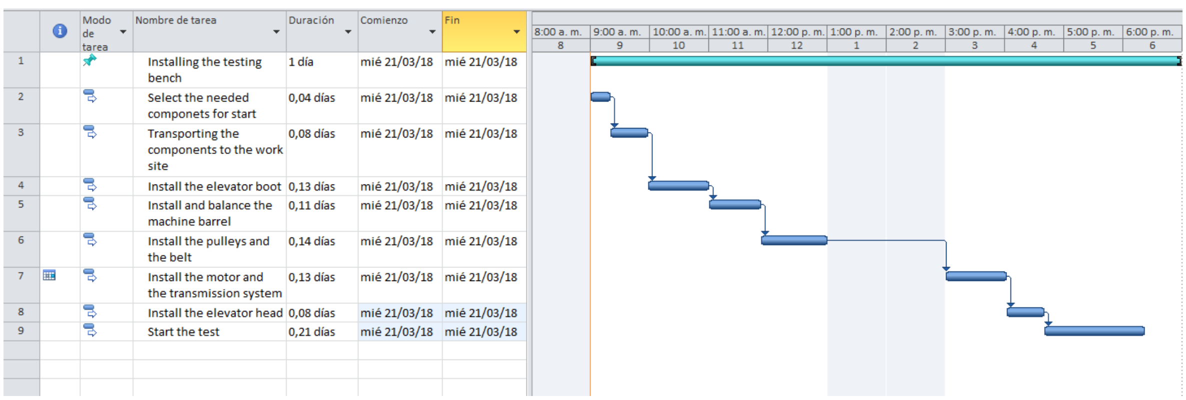


Figure 4.7.3.1. Alternative 3 CAD.

COMPONENT	DESCRIPTION	QUANTITY
Manual transmission (gearbox)	Only upon request	1
Belt pulleys	Congress Fixed Bore V-Belt Pulleys	4
Transmission belt	Dayton 4L/A V-Belt	2
Buckets	High Density Polyethylene Elevator Buckets 5 x 4	10
Pulley bearings	Tritan 4-Bolt Flange Bearings	4
Shaft bearings	Dayton Pillow Block Bearings	4

Table 4.7.3.2 BOM of alternative 3.



	Modo de tarea	Nombre de tarea	Duración	Comienzo	Fin
1		Installing the testing bench	1 día	mié 21/03/18	mié 21/03/18
2		Select the needed componets for start	0,04 días	mié 21/03/18	mié 21/03/18
3		Transporting the components to the work site	0,08 días	mié 21/03/18	mié 21/03/18
4		Install the elevator boot	0,13 días	mié 21/03/18	mié 21/03/18
5		Install and balance the machine barrel	0,11 días	mié 21/03/18	mié 21/03/18
6		Install the pulleys and the belt	0,14 días	mié 21/03/18	mié 21/03/18
7		Install the motor and the transmission system	0,13 días	mié 21/03/18	mié 21/03/18
8		Install the elevator head	0,08 días	mié 21/03/18	mié 21/03/18
9		Start the test	0,21 días	mié 21/03/18	mié 21/03/18

4.7.3.3. Schedule of alternative 3.

4.8 ALTERNATIVES EVALUATION

All the alternatives were commented with Superbrix design team, the feedback received was one of the main inspiration, but for an analytic and rational selection among all the alternatives, the software Expert Choice® was used. The software employs the Analytic Hierarchy Process (AHP). It allows the decision maker to set priorities, providing a structured technique for complex decision making. The program generates a weight for each criterion included in the pairwise comparison, allows the decision maker to assign a score to each criterion for each alternative, and calculates a final score for each alternative. A higher score indicates a better overall performance.

Figures 4.8.1-4 show the behavior of the alternatives as generated by the software according to the criteria outlined in the pairwise comparison.

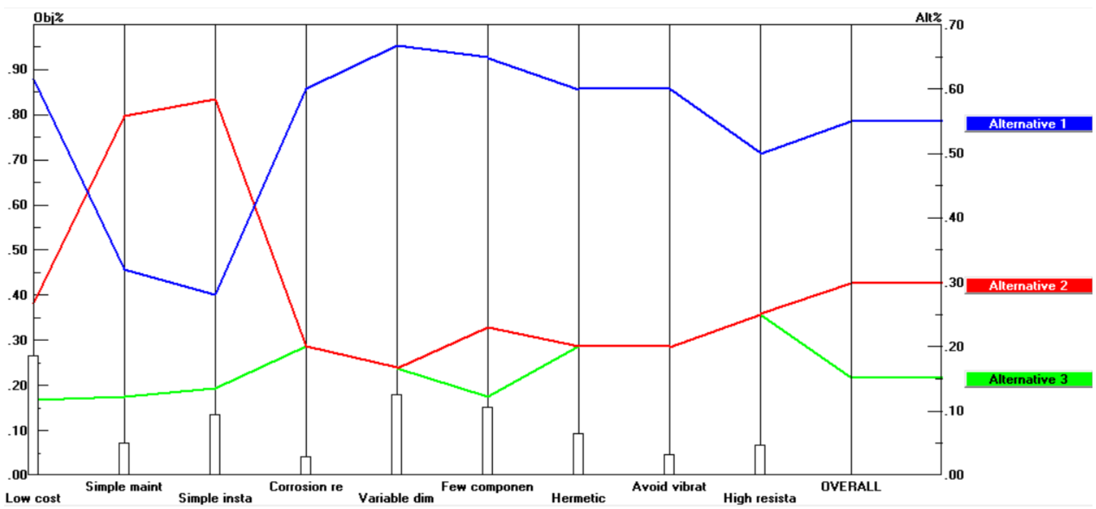


Figure 4.8.1 Performance sensitivity.

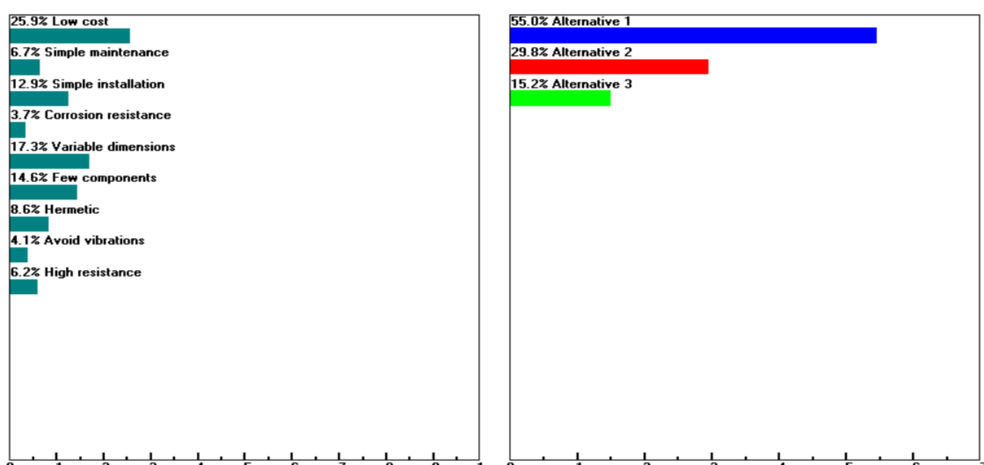


Figure 4.8.2. Dynamic Sensitivity.

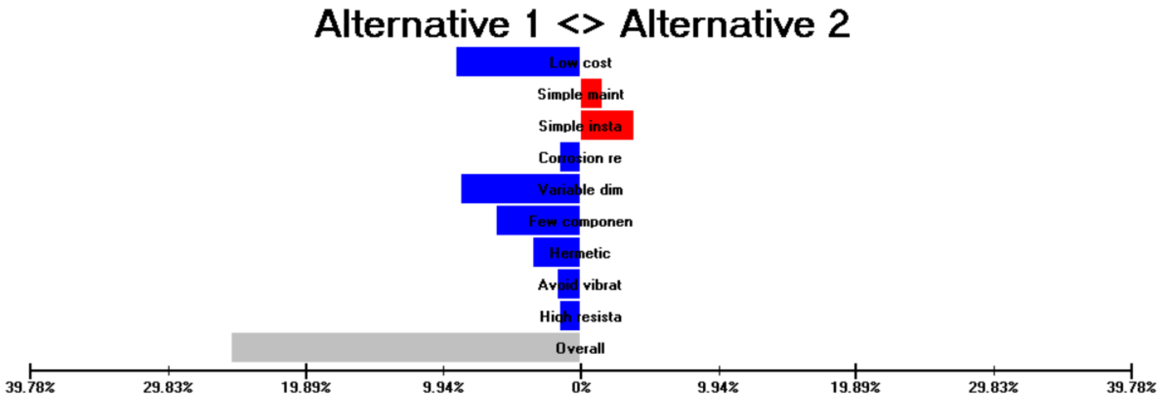


Figure 4.8.3. Weight comparison between alternatives 1 and 2.

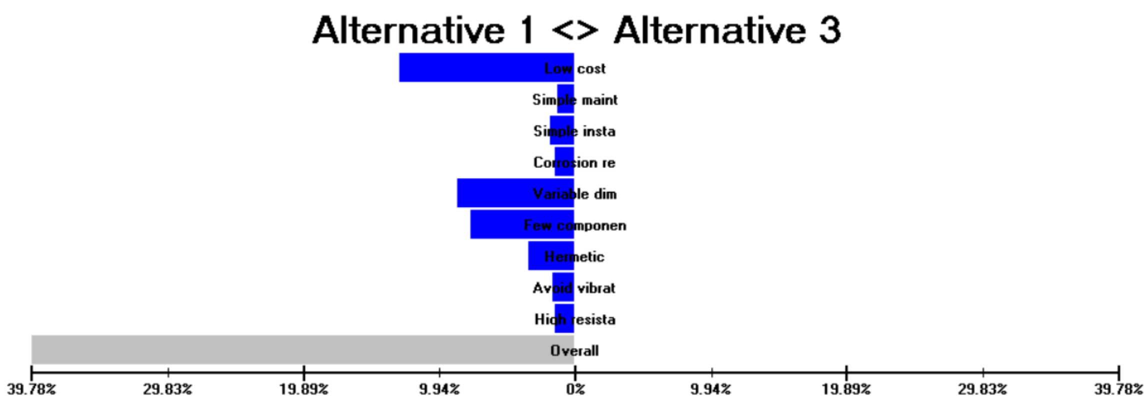


Figure 4.8.4. Weight comparison between alternatives 1 and 3.

Although alternatives 2 and 3 score higher in simple maintenance and installation, alternative 1 receives a higher overall score. Alternative 1 is 40% better than alternative 3 and 25% better than alternative 2, indicating that this design will provide better results.

4.9 SPECIFICATIONS DEFINITION'S CALCULATIONS MEMORY

4.9.1 Specifications and constraints by the client

To achieve realistic results and maintain cost effectiveness, the test bench will utilize some existing components from bucket elevator models manufactured by SuperBrix. For cost and logistical reasons, the suppliers for external components are also recommended.

To define the operation conditions of the bucket elevator, some parameters were given by the client, while others were found through calculations. These parameters are outlines in *table 4.9.1.1*.

Pulley diameter	41 cm
Distance between centers of the pulleys	87,5 cm
Bucket dimensions	5 in x 4 in
Bucket capacity	566 cm^3
Paddy rice density	576 $\frac{kg}{m^3}$
Bucket filling efficiency	75%

Table 4.9.1.1. Specifications defined by the client.

4.9.2 Power and torque required

The forces present on the elevator are identified to calculate the power requirement of it. Analyzing the elevator configuration, it is concluded that the only forces that do work are the weight of the rice and the dredge load; this is because both forces act only in one side of the elevator. The weight of the belt and the weight of the buckets are present in both sides of the elevator with the same magnitude, then they don't do work.

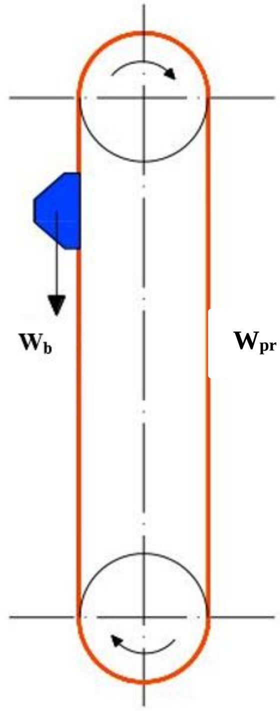


Figure 4.9.2.1. Free body diagram of the elevator.

To have conservative results, it is assumed that all the buckets are in one side of the elevator and the weight of the rice is calculated with the following equation.

$$W_{pr} = 1{,}1RD_{pr}\rho_w N_b V_{b,wl} g$$

Where ρ_w is the density of water in International System units.

$$W_{pr} = 1{,}1 * 0{,}576 * 1000\ \frac{kg}{m^3} * 10 * 35{,}8\ in^3 * \frac{(0{,}0254\ m)^3}{1\ in^3} * 9{,}8\ \frac{m}{s^2}$$

$$W_{pr} = 36{,}43\ N$$

The dredge load is obtained using the next equation [32].

$$F_D = \frac{99\ \frac{m^2}{s^2} RD_{pr}\rho_w V_{b,wl}}{Sp}$$

$$F_D = \frac{99\ \frac{m^2}{s^2} * 0{,}576 * 1000\ \frac{kg}{m^3} * 35{,}8\ in^3 * \frac{(0{,}0254\ m)^3}{1\ in^3}}{0{,}3\ m}$$

$$F_D = 111{,}51\ N$$

The next free body diagram shows the forces acting on the pulley.

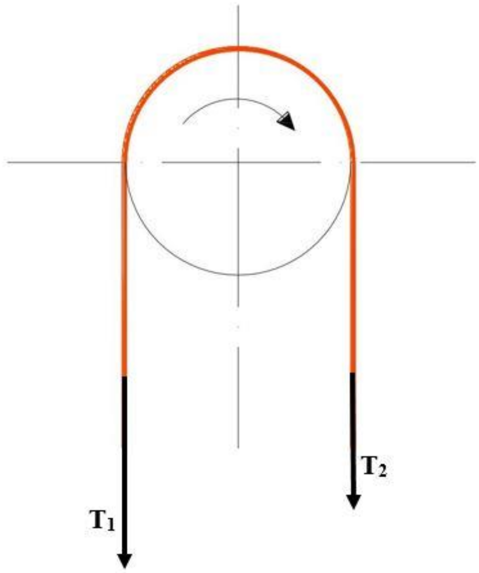


Figure 4.9.2.2. Free body diagram of the pulley.

The maximum tension T_1 is equal to the sum of the weight of the rice and the dredge load.

$$T_1 = 36{,}43\ \mathrm{N} + 111{,}51\ \mathrm{N} = 147{,}94\ \mathrm{N}$$

The relation between tensions is defined by the capstan equation.

$$\frac{T_1}{T_2} = e^{\mu\theta}$$

Where θ is the contact angle in radians and μ is the coefficient of friction between the belt and the pulley. For a rubber belt and rubber pulley lagging, the coefficient of friction is equal to 0,25 [26].

$$T_2 = \frac{147{,}94\ \mathrm{N}}{e^{0{,}25\pi}} = 67{,}45\ \mathrm{N}$$

It is concluded that the mass and acceleration of the pulley will not add an important contribution to the power requirement; this contribution will be within the service factor and motor efficiency assumptions. Thus, a sum of moments at steady state is made in the center of the pulley.

$$\Sigma_M = \frac{(T_1 - T_2)D_p}{2} - To = 0$$

Where To is the torque applied to the pulley by the motor.

It is also known that the power and the linear velocity of the belt are calculated with the next equations.

$$P_{mot,t} = To\omega_p$$

$$v_b = \frac{D_p \omega_p}{2}$$

Replacing the sum of moments and the linear velocity of the belt in the power formula, the following expression is obtained. However, for calculations, it is taken the velocity of the buckets in order to obtain conservative results.

$$P_{mot,t} = (T_1 - T_2)v_b$$

$$P_{mot,t} = (147{,}94\ N - 67{,}45\ N) * 3{,}21\ {}^{m}/_{s} = 258{,}37\ W$$

The motor efficiency is equal to 0,8 and a factor of service of 1,3 is taken. Then the actual power requirement is calculated.

$$P_{mot,r} = \frac{258{,}37\ W * 1{,}3}{0{,}8} = 419{,}85\ W$$

Using the page DriveGate of SEW Eurodrive, it is found that the best commercial solution for the specifications stated above is the AC Motor R17DRS80M4/TF with an output speed and torque of 124 rpm and 85 Nm respectively and power of 1100 W.

With the new power, the tensions on the belt are recalculated to design the components of the testing bench.

$$\left(T_{1,r} - T_{2,r}\right) = \frac{P_{mot,r}}{v_b} = \frac{1100\ W}{3{,}21\ {}^{m}/_{s}}$$

$$\frac{T_{1,r}}{T_{2,r}} = e^{\mu\theta} = e^{0{,}25\pi}$$

Solving the equations, the tension values are obtained.

$$T_{1,r} = 630{,}94\ N$$

$$T_{2,r} = 287{,}67\ N$$

4.9.3 Bearings selection

The main shaft will have two bearings to provide adequate support, which comes from the bending moment produced by the loads.

The selection will be made taking both the SKF catalogue selection procedure and the calculated loads into consideration.

The first approach will be made with the calculated diameter of the shaft. Then, the load and speed requirements will be verified. *Table 4.9.3.1* lists all the adequate 30mm options, one of which will be chosen.

Principal dimensions			Basic load ratings		Fatigue load limit	Speed ratings		Mass	Designations	
			dynamic	static		Reference speed	Limiting speed		Bearing with standard cage	Alternative standard cage[1)]
d	D	B	C	C_0	P_u					
mm			kN		kN	r/min		kg	–	
25	52	18	39	34	4,25	14 000	16 000	0,16	* NU 2205 ECP	ML
cont.	52	18	39	34	4,25	14 000	16 000	0,17	* NJ 2205 ECP	ML
	52	18	39	34	4,25	14 000	16 000	0,17	* NUP 2205 ECP	ML
	62	17	46,5	36,5	4,55	12 000	15 000	0,23	* NU 305 ECP	J, ML
	62	17	46,5	36,5	4,55	12 000	15 000	0,24	* NJ 305 ECP	J, ML
	62	17	46,5	36,5	4,55	12 000	15 000	0,25	* NUP 305 ECP	J, ML
	62	17	46,5	36,5	4,55	12 000	15 000	0,24	* N 305 ECP	–
	62	24	64	55	6,95	12 000	15 000	0,34	* NU 2305 ECP	J, ML
	62	24	64	55	6,95	12 000	15 000	0,35	* NJ 2305 ECP	J, ML
	62	24	64	55	6,95	12 000	15 000	0,36	* NUP 2305 ECP	J, ML
30	55	13	17,9	17,3	1,86	15 000	15 000	0,12	NU 1006	–
	62	16	44	36,5	4,5	13 000	14 000	0,2	* NU 206 ECP	J, ML,PH
	62	16	44	36,5	4,5	13 000	14 000	0,21	* NJ 206 ECP	J, ML,PH
	62	16	44	36,5	4,5	13 000	14 000	0,21	* NUP 206 ECP	J, ML,PH
	62	16	44	36,5	4,5	13 000	14 000	0,2	* N 206 ECP	–
	62	20	55	49	6,1	13 000	14 000	0,26	* NU 2206 ECP	J, ML,PH
	62	20	55	49	6,1	13 000	14 000	0,26	* NJ 2206 ECP	J, ML,PH
	62	20	55	49	6,1	13 000	14 000	0,27	* NUP 2206 ECP	J, ML,PH
	72	19	58,5	48	6,2	11 000	12 000	0,36	* NU 306 ECP	J, M, ML
	72	19	58,5	48	6,2	11 000	12 000	0,37	* NJ 306 ECP	J, M, ML
	72	19	58,5	48	6,2	11 000	12 000	0,38	* NUP 306 ECP	J, M, ML
	72	19	58,5	48	6,2	11 000	12 000	0,36	* N 306 ECP	–
	72	27	83	75	9,65	11 000	12 000	0,53	* NU 2306 ECP	ML
	72	27	83	75	9,65	11 000	12 000	0,54	* NJ 2306 ECP	ML
	72	27	83	75	9,65	11 000	12 000	0,55	* NUP 2306 ECP	ML
	90	23	60,5	53	6,8	9 000	11 000	0,75	NU 406	MA
	90	23	60,5	53	6,8	9 000	11 000	0,79	NJ 406	MA

Figure 4.9.3.1 SKF catalogue [31]

Figure 4.9.3.1 is a schematic illustrating the specified dimensions for the diverse types of references. The selected bearing has as reference NU1006.

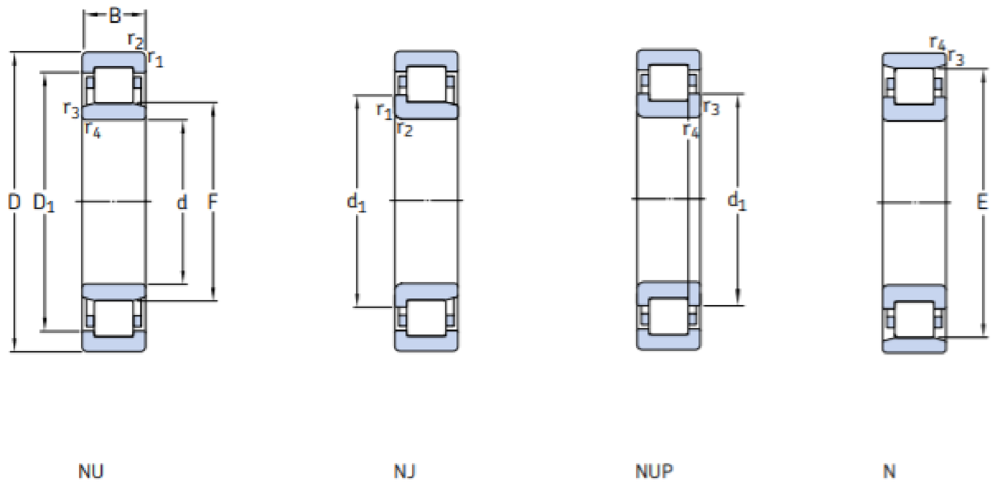


Figure 4.9.3.1 SKF Bearing types: NU, NJ, NUP, N [31]

The minimum load that the cylindrical roller bearing can support is given by the manufacturer and is calculated as it follows

$$F_{rm} = K_r * \left(6 + \frac{4 * n}{n_r}\right) * \left(\frac{d_m}{100}\right)^2$$

The minimum load factor (Kr) depends on the standard and the alternative standard cage and in this case will have a value of 1. Also, n is the rotational speed that the bearing will experiment and n_r is the reference speed extracted from the product tables.

The next calculation is the mean diameter d_m which is given by

$$d_m = \frac{d + D}{2}$$

$$d_m = \frac{30 + 55}{2}$$

$$d_m = 57.5$$

The next step is the calculation of the minimum load

$$F_{rm} = 1 * \left(6 + \frac{4 * 124}{15000}\right) * \left(\frac{57.5}{100}\right)^2$$

$$F_{rm} = 1.994\ kN\ \approx 2\ kN$$

As the weight of the components supported by the bearing, together with the external forces exceed the requisite of minimum load, the bearing must not be subjected to an additional radial load.

The shaft will not be subjected to representative axial loads but the calculations to know the maximum supportable dynamic axial load will be made, just to ensure that this value will never be exceeded.

The first step is to calculate the surface of outside and bore diameter

$$\pi * B * (D + d) = 3471.45\, mm^2 \leq 50.000\, mm^2$$

The corresponding formula is:

$$F_{ap} = \frac{K_1 * C_o * 10^4}{n * (d + D)} - K_2 * F_{rm}$$

Where K_1 and K_2 are lubrication constants; for single row cylindrical roller bearing the respective values will be 1 and 0.1, assuming grease lubrication.

C_o is the basic static load rating, extracted from the product table, equal to 17.3 kN in this case.

With these values known, the calculation can be made:

$$F_{ap} = \frac{1 * 17.3 * 10^4}{124 * (30 + 55)} - 0.1 * 2$$

$$F_{ap} = 16.21\, kN$$

This value is much higher than any expected value, so the selected bearings (SKF NU1006) will be more than adequate.

4.9.4 Chain Selection

To select the chain, it is necessary to consider the main parameters of the motor and transmission ratio that is to be applied. Due to the selected motor's reduction coinciding with the maximum speed required for the testing bench (specified by SuperBrix), the specified ratio for this chain transmission was 1 to 1.

Chain selection was made by applying the Renold's Chain Selector. To use this selector, it was also necessary to specify the center distance and other conditions such as loading classification, lubrication and environmental conditions.

Input parameters are listed below

$$P = 1{,}1\, kw$$

$$Number\ of\ teeth = 19, (For\ driving\ and\ driver\ sprocket)$$

$$Centre\ Distance = 600\ mm$$

The loading classification was specified as smooth running for driving machine and moderate shock for the driven machine. The environmental conditions were set as indoor application and the lubrication was considered as inadequate in order to be conservative. Finally, the final parameters for the geometry and chain commercial specification (serial number) were obtained. It's important to note that due to the iterative process applied by selectors, some geometrical parameter can vary. Also, information of the sprockets can be obtained from the Renold's Chain Selector.

Results are listed below in *Figure 4.9.4.1* and *Table 4.9.4.2.*

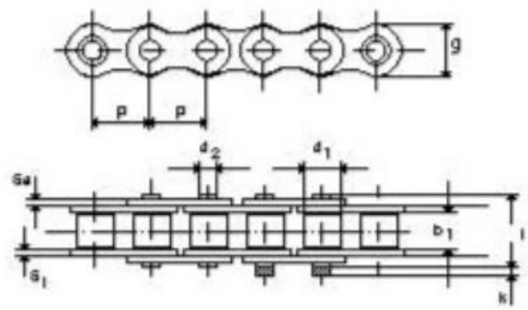


Figure 4.9.4.1. Chain dimensions [30]

Chain Drive	
Pitch, p (mm)	15,875
Number of links, X	94
Centre distance, (mm)	595,31
Pin length, l (mm)	20,4
Height,g (mm)	14,6
Roller diameter, d1	10,16
Mass, q (kg/m)	1
Sprockets (both driving and driven)	
Number of teeth	19
pitch circle diameter (mm)	96,45

Table 4.9.4.2. Chain parameters

These results were later implemented for CAD representation. The chain specification is also listed on the final alternative's bill of material for the estimative alternative cost.

4.9.5 Drive pulley coupling selection

Transmitting power from the shaft to the pully requires a coupling. When making a coupling selection, we must keep in mind that the test bench requires easy assembly and disassembly. A keyless bushing is used in most applications where a coupling is needed between a shaft and a bored component.

The shaft size may help to immediately determine which bushing can be selected. In this case a Fenner Drives® B-LOC keyless bushing is adequate, and their product catalogue will be used for the selection. The installation method of this type consists of a plurality of screws. To complete this installation, it is only necessary to tighten the screws to the specified installation torque and the connection is complete. Removal is the same process, loosening the screws to disengage the unit. The advantage of having many screws is that the force needed to draw the mating tapers will be distributed among these, resulting in a lower installation torque.

B-LOC keyless bushing are made from treated carbon and alloy steels, so if the application is in a corrosive environment, the corrosion resistance can be improved through sealing with grease or silicone.

The portion of the shaft where the pulley will be mounted has a diameter of 32mm. The shaft will transmit 84.71 $N * m$ of torque. These two parameters will serve as selection criteria.

The selected alternative is shown in *table 4.9.5.1* extracted from the product catalogue of Fenner Drives®

B106 — Metric

Part Number	d (mm)	D (mm)	D_1 (mm)	L (mm)	L_1 (mm)	L_2 (mm)	Locking Screws Qty	Locking Screws Size	M_a Install Torque (Nm)	M_t Maximum Transmitted Torque (Nm)	Th Maximum Transmitted Thrust (N)	P_h Hub Pressure (N/mm^2)	Shipping Weight (kg)
T601014	14	28	32	14	20.5	17	4	M4 x 12	5	68	9713	66	0.1
T601015	15	28	32	14	20.5	17	4	M4 x 12	5	73	9713	66	0.1
T601018	18	47	52	17	28.5	22.5	5	M6 x 20	16	236	26234	87	0.3
T601019	19	47	52	17	28.5	22.5	5	M6 x 20	16	249	26234	87	0.3
T601020	20	47	52	17	28.5	22.5	5	M6 x 20	16	262	26234	87	0.3
B601022	22	47	52	17	28.5	22.5	5	M6 x 20	16	289	26234	87	0.3
T601024	24	50	56.5	17	28.5	22.5	6	M6 x 20	16	378	31481	98	0.3
B601025	25	50	56.5	17	28.5	22.5	6	M6 x 20	16	394	31481	98	0.3
B601028	28	55	61.5	17	28.5	22.5	6	M6 x 20	16	441	31481	89	0.4
B601030	30	55	61.5	17	28.5	22.5	6	M6 x 20	16	472	31481	89	0.3
T601032	32	60	66.5	17	28.5	22.5	8	M6 x 20	16	672	41975	109	0.4
B601035	35	60	66.5	17	28.5	22.5	8	M6 x 20	16	735	41975	109	0.4
T601038	38	65	71.5	17	28.5	22.5	8	M6 x 20	16	798	41975	101	0.5
B601040	40	65	71.5	17	28.5	22.5	8	M6 x 20	16	839	41975	101	0.5
T601042	42	75	83.5	20	34.5	26.5	7	M8 x 25	41	1515	72167	128	0.8
B601045	45	75	83.5	20	34.5	26.5	7	M8 x 25	41	1624	72167	128	0.7
T601048	48	80	88.5	20	34.5	26.5	7	M8 x 25	41	1732	72167	120	0.8
B601050	50	80	88.5	20	34.5	26.5	7	M8 x 25	41	1804	72167	120	0.8
B601055	55	85	93.5	20	34.5	26.5	8	M8 x 25	41	2268	82476	129	0.8
B601060	60	90	98	20	34.5	26.5	8	M8 x 25	41	2474	82476	122	0.9

Figure 4.9.5.1. Fenner product catalogue B-LOC keyless bushing [28]

The T601032 bushing can transmit up to 672 $N * m$ of torque, much larger than the required torque, with an installation torque of just 16 $N * m$, less that the transmission torque of the shaft. This proves this is an adequate choice. The maximum axial thrust is in check too. The dimensions are shown in the table and are the ones of the following diagram.

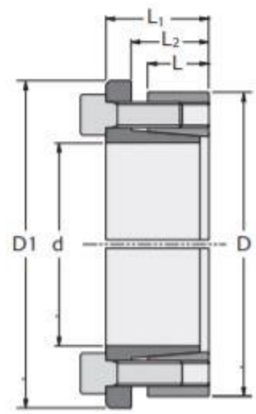


Figure 4.9.5 B-LOC keyless dimensions [28]

The dimensions of the product are also fitting for the available space in the elevator. The installation will require 8 M6 X 20 screws, as specified in the product table and the method of union between the product and the pulley will be welding.

4.9.6 Shaft design

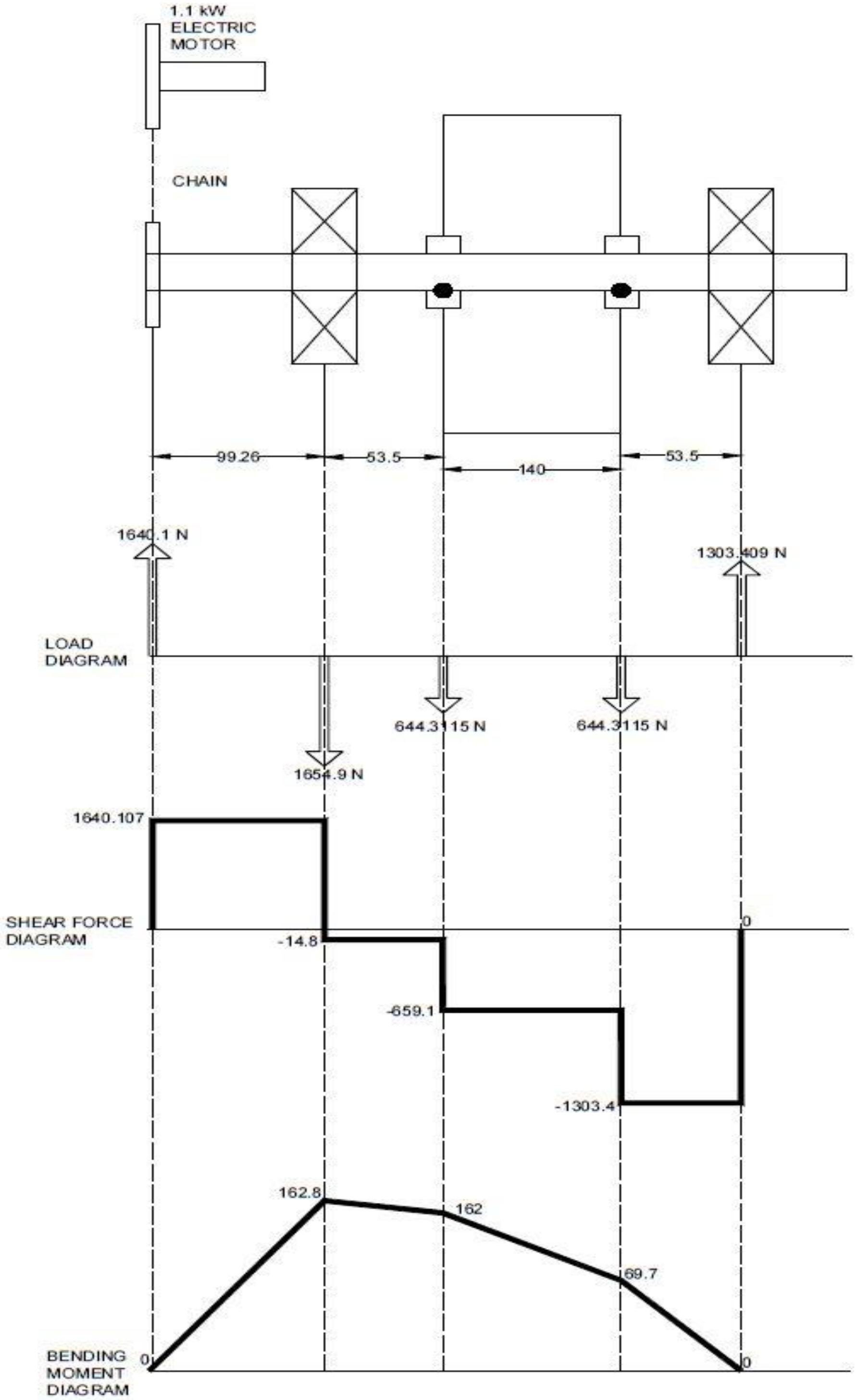


Figure 4.9.6.1. Forces and moments on the shaft.

According to the design logic diagram shown in *figure 4.9.6.2,* Modified Goodman method has been chosen, considering that cyclic loads and stress are presented. The method is applied using the following equation.

$$\frac{1}{N} = \frac{\sigma_{fMises}}{S_L} + \frac{\sigma_{sMises}}{S_{ut}}$$

Where N is the safety factor, σ_{fMises} is the Von Mises yield criterion using fluctuating loads, σ_{sMises} is the Von Mises yield criterion using static loads, S_L is the fatigue limit and S_{ut} is the ultimate tensile strength of the material [26].

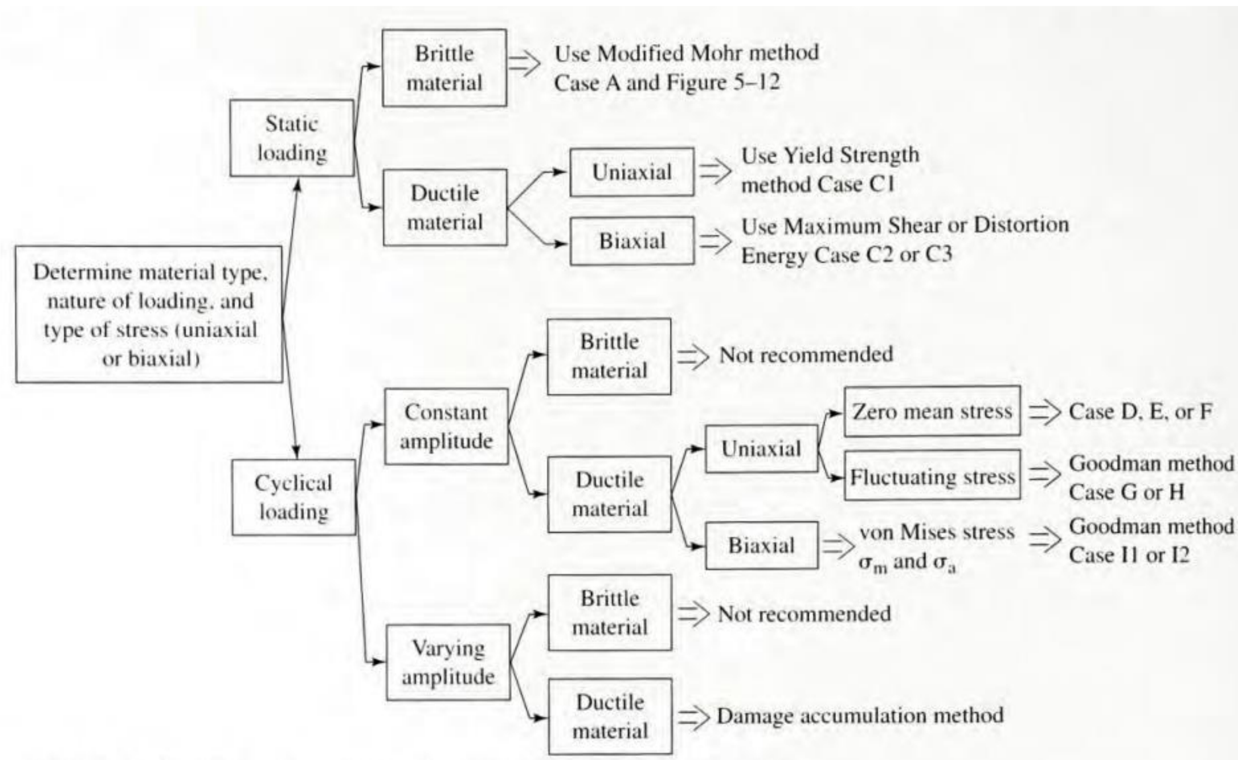


Figure 4.9.6.2. Design logic diagram [27].

The critical point is obtained from the bending, torsion and shear diagrams; it is located on the first bearing. Analyzing the movement of the shaft and making moment and loads diagrams for the critical point, it can be concluded that bending and shear loads are fluctuating while torsion loads stay in the same value; in the calculations, shear loads can be ignored because they don't represent an important addition to the stress on the shaft.

The next equations are used to calculate the Von Mises yield criterion for both fluctuating and static loads.

$$\sigma_{fMises} = \sqrt{\left(K_f \frac{M_f C}{I}\right)^2 + 3\left(K_{fs} \frac{T_f C}{J}\right)^2}$$

$$\sigma_{sMises} = \sqrt{\left(K_f \frac{M_s C}{I}\right)^2 + 3\left(K_{fs} \frac{T_s C}{J}\right)^2}$$

Where K_f and K_{fs} are load factors, I is the second moment of area, J is the polar moment of inertia, C is the radius of the shaft and M and T represent the bending and torsion moments [26].

As obtained from the diagrams of the critical point, is known that there is no static bending moment and the shear load is ignored due to the reason stated before. Then, knowing the equation to find the second moment of area and the polar moment of inertia of a circle, the following expressions are obtained:

$$\sigma_{fMises} = \frac{32 K_f M_f}{\pi d^3}$$

$$\sigma_{sMises} = \sqrt{3}\,\frac{16 K_{fs} T_s}{\pi d^3}$$

Replacing these equations on the Modified Goodman method equation, the following expression is found:

$$\frac{1}{N} = \frac{16}{\pi d^3}\left(\frac{2 K_f M_f}{S_L} + \sqrt{3}\,\frac{K_{fs} T_s}{S_{ut}}\right)$$

To determine the load factors, ultimate tensile strength and fatigue limit, the material of the shaft must be defined. The client stated that they use shafts made with carbon steel AISI-SAE 1045. According to *figure 4.9.6.3,* this material has an ultimate tensile strength of 725 MPa and a hardness of 225 HB.

Grade (a)	Orientation (e)	Description (f)	Hardness HB	Tensile Strength S_{ut} MPa	ksi	Reduction in Area %	True Strain at Fracture ε_f	Modulus of Elasticity E GPa	10^6 psi	Fatigue Strength Coefficient σ'_f MPa	ksi	Fatigue Strength Exponent b	Fatigue Ductility Coefficient ε'_F	Fatigue Ductility Exponent c
A538A (b)	L	STA	405	1515	220	67	1.10	185	27	1655	240	−0.065	0.30	−0.62
A538B (b)	L	STA	460	1860	270	56	0.82	185	27	2135	310	−0.071	0.80	−0.71
A538C (b)	L	STA	480	2000	290	55	0.81	180	26	2240	325	−0.07	0.60	−0.75
AM-350 (c)	L	HR, A		1315	191	52	0.74	195	28	2800	406	−0.14	0.33	−0.84
AM-350 (c)	L	CD	496	1905	276	20	0.23	180	26	2690	390	−0.102	0.10	−0.42
Gainex (c)	LT	HR sheet		530	77	58	0.86	200	29.2	805	117	−0.07	0.86	−0.65
Gainex (c)	L	HR sheet		510	74	64	1.02	200	29.2	805	117	−0.071	0.86	−0.68
H-11	L	Ausformed	660	2585	375	33	0.40	205	30	3170	460	−0.077	0.08	−0.74
RQC-100 (c)	LT	HR plate	290	940	136	43	0.56	205	30	1240	180	−0.07	0.66	−0.69
RQC-100 (c)	L	HR plate	290	930	135	67	1.02	205	30	1240	180	−0.07	0.66	−0.69
10B62	L	Q&T	430	1640	238	38	0.89	195	28	1780	258	−0.067	0.32	−0.56
1005-1009	LT	HR sheet	90	360	52	73	1.3	205	30	580	84	−0.09	0.15	−0.43
1005-1009	LT	CD sheet	125	470	68	66	1.09	205	30	515	75	−0.059	0.30	−0.51
1005-1009	L	CD sheet	125	415	60	64	1.02	200	29	540	78	−0.073	0.11	−0.41
1005-1009	L	HR sheet	90	345	50	80	1.6	200	29	640	93	−0.109	0.10	−0.39
1015	L	Normalized	80	415	60	68	1.14	205	30	825	120	−0.11	0.95	−0.64
1020	L	HR plate	108	440	64	62	0.96	205	29.5	895	130	−0.12	0.41	−0.51
1040	L	As forged	225	620	90	60	0.93	200	29	1540	223	−0.14	0.61	−0.57
1045	L	Q&T	225	725	105	65	1.04	200	29	1225	178	−0.095	1.00	−0.66
1045	L	Q&T	410	1450	210	51	0.72	200	29	1860	270	−0.073	0.60	−0.70
1045	L	Q&T	390	1345	195	59	0.89	205	30	1585	230	−0.074	0.45	−0.68
1045	L	Q&T	450	1585	230	55	0.81	205	30	1795	260	−0.07	0.35	−0.69
1045	L	Q&T	500	1825	265	51	0.71	205	30	2275	330	−0.08	0.25	−0.68
1045	L	Q&T	595	2240	325	41	0.52	205	30	2725	395	−0.081	0.07	−0.60
1144	L	CDSR	265	930	135	33	0.51	195	28.5	1000	145	−0.08	0.32	−0.58

Figure 4.9.6.3. Properties of some materials [26].

It is known from the industry that shaft sizes range from 20 mm to 80 mm for high capacity elevators; as a seed value, a diameter of 30 mm is taken. The fatigue limit is obtained from the following equation:

$$S_L = 0{,}5 k_a k_b k_c k_e S_{ut}$$

Where k takes the value of different factors given by the geometry and operation conditions of the shaft [26].

For an optimum operation of the shaft, it must be polished to avoid undesirable stress concentrators or binding; k_a is equal to 0,9 in this condition according to *figure 4.9.6.4*.

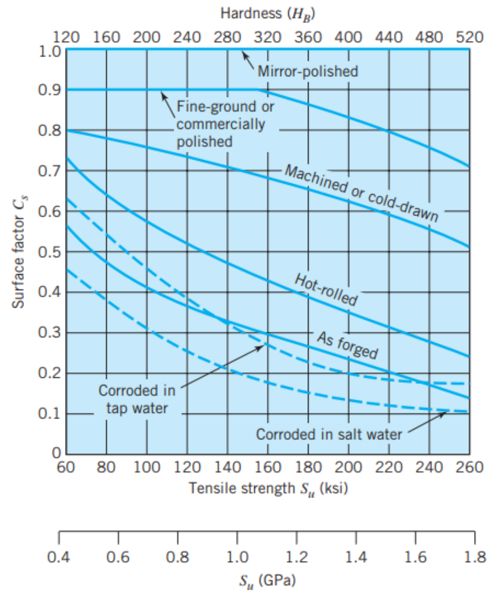


Figure 4.9.6.4. Surface factor [28].

The value of k_b is obtained from the following equation:

$$k_b = 1{,}24d^{-0{,}107}$$

$$k_b = 1{,}24 * 30^{-0{,}107} = 0{,}86$$

When the shaft is operating under fluctuating bending loads k_c takes a value of 1. The reliability of the shaft should be at least 90%, then k_e is equal to 0,897 [26].

$$S_L = 0{,}5 * 0{,}9 * 0{,}86 * 1 * 0{,}897 * 725 \text{ MPa} = 251{,}68 \text{ MPa}$$

The shaft is designed with variable diameter to allow easy installation of the bearings. There are two changes of section; the first is imperceptible, allowing the bearing to go through the shaft and the second is to delimitate the bearing position. These are considered stress concentrators. However, these concentrators are not located at the critical point; to have conservative calculations, it is assumed that the critical point also has the greater stress concentrator which is the shoulder that delimitates the bearing position.

The stress concentrator is obtained from the next equation:

$$K = 1 + q(K_t - 1)$$

Where K_t is a factor found in charts depending on the type of stress presented on the shaft and q is the notch sensitivity, also found in charts depending on the type of concentrator. This equation can be used to calculate both K_f and K_{fs} [26].

A relationship is assumed between diameters of 1,08 on the change of section and the shoulder radius of 0,8 mm (this radius is determined by the minimum external diameter of the bearing); the relation between the shoulder radius and the smaller diameter is equal to 0,03. From *figure 4.2.6.5* and *figure 4.2.6.6*, shown below, K_t and K_{ts} are found. K_t is equal to 2 and K_{ts} is equal to 1,37.

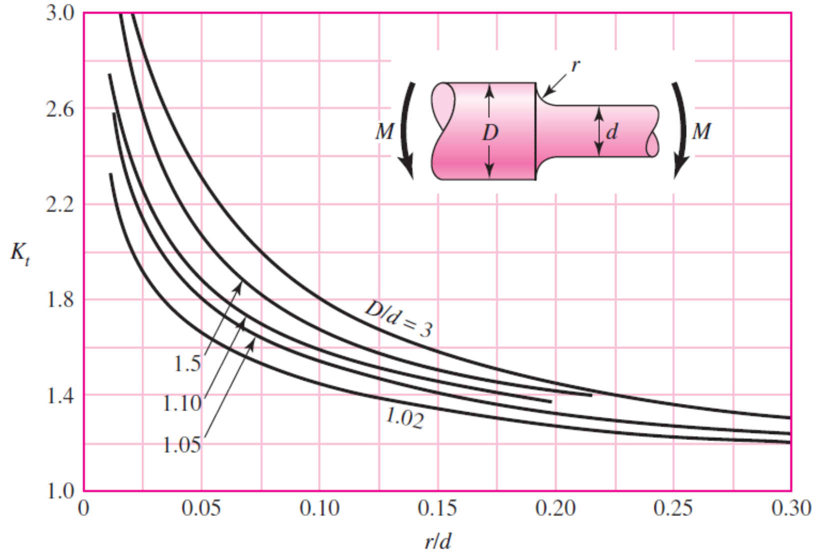


Figure 4.9.6.5. Shaft with shoulder in bending [26].

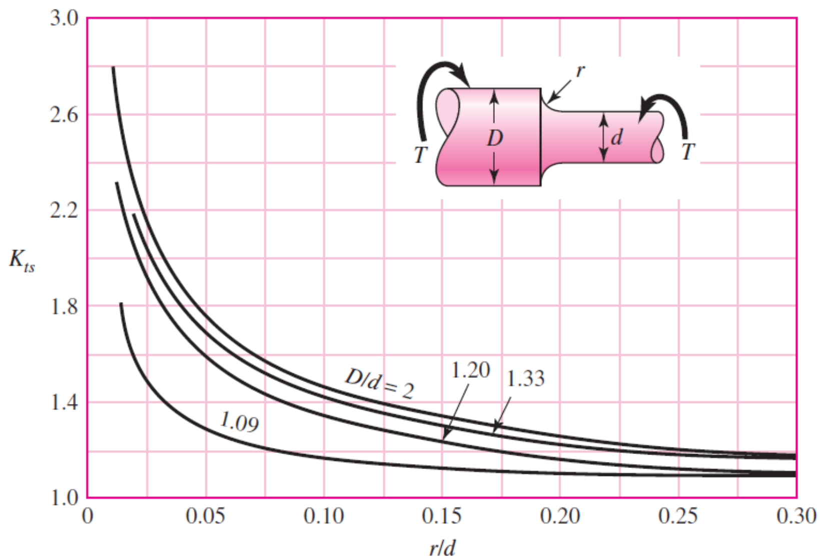


Figure 4.9.6.6. Shaft with shoulder in torsion [26].

To obtain the notch sensitivity the shoulder radius of 0,8 mm is used. From *figures 4.9.6.7* and *4.9.6.8*, we find that q is equal to 0,75 and q_s is equal to 0,83.

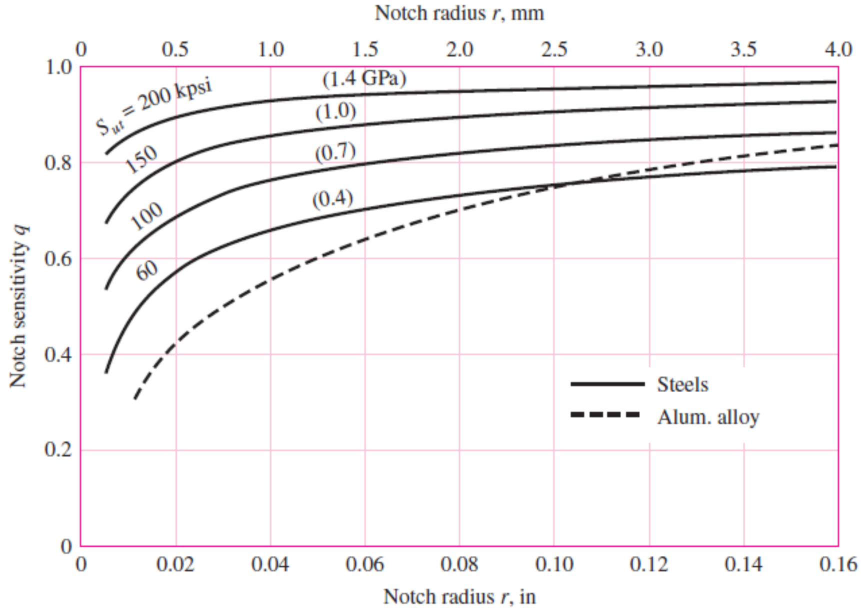


Figure 4.9.6.7. Notch sensitivity in bending [26].

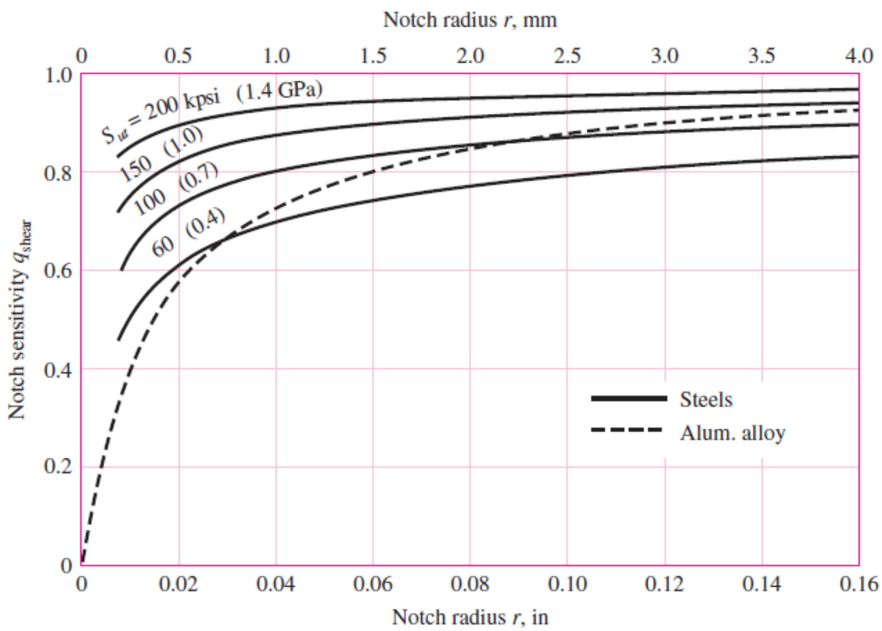


Figure 4.9.6.8. Notch sensitivity in torsion [26].

K_f and K_{fs} are then calculated:

$$K_f = 1 + q(K_t - 1)$$

$$K_f = 1 + 0{,}77(2 - 1) = 1{,}77$$

$$K_{fs} = 1 + q_s(K_{ts} - 1)$$

$$K_{fs} = 1 + 0{,}82(1{,}37 - 1) = 1{,}3$$

Concentrators and moment values are replaced in the modified Goodman equation to find the safety factor:

$$\frac{1}{N} = \frac{16}{\pi(30\ \text{mm})^3}\left(\frac{2 * 1{,}77 * 162800\ \text{Nmm}}{251{,}68\ \text{MPa}} + \sqrt{3}\frac{1{,}3 * 84710\ \text{Nmm}}{725\ \text{MPa}}\right)$$

$$N = 2{,}08$$

This safety factor is acceptable for the shaft design and guarantees that it won't fail due to fatigue stress.

Using SolidWorks, the loads on the shaft were simulated in order to check if the calculations were near to reality. The analyses can be found in *figures 4.9.6.9 - 4.9.6.11*. Both arithmetic and software analyses gave positive results.

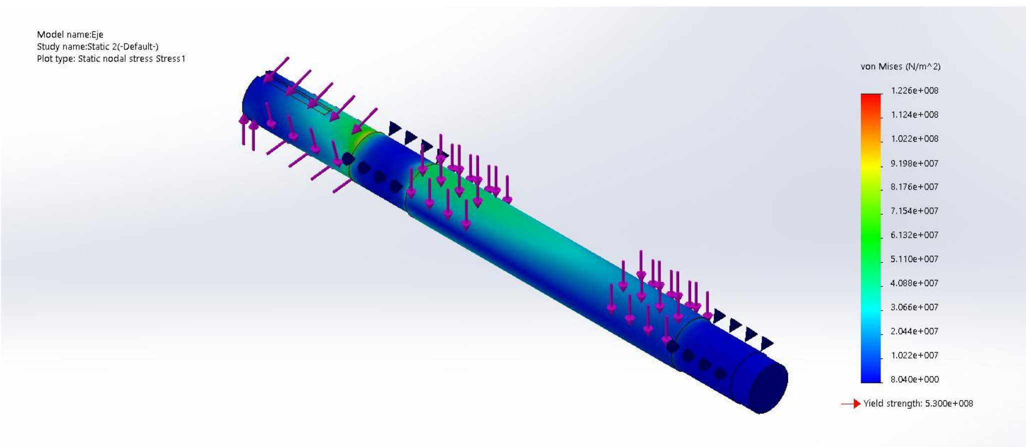


Figure 4.9.6.9. Static loads on the shaft. Solid Works

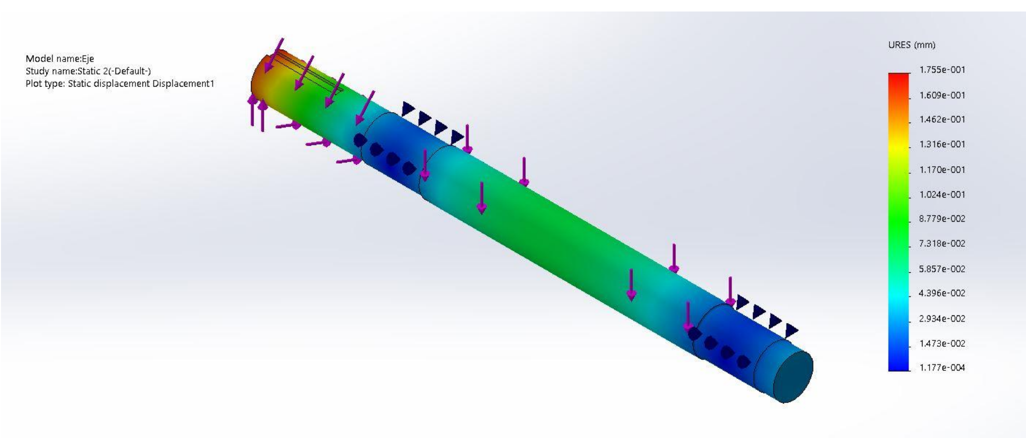


Figure 4.9.6.10. Deformations on the shaft. Solid Works

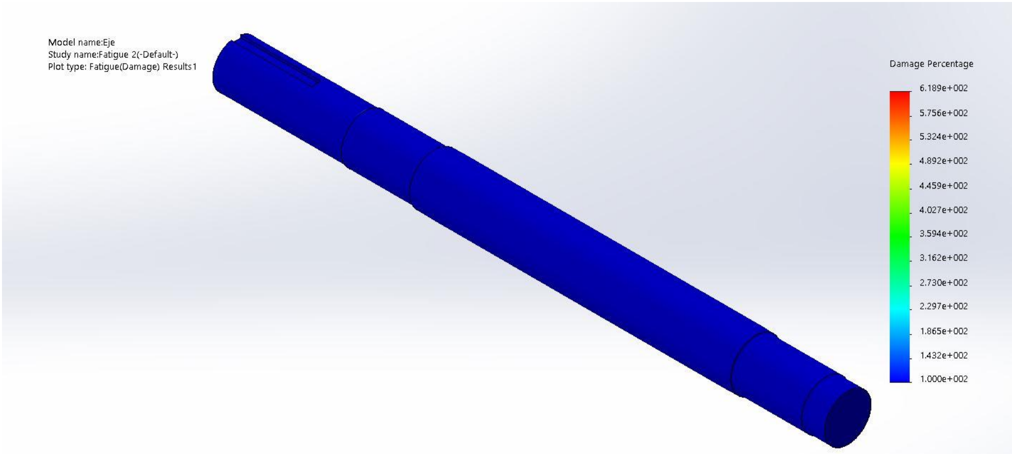


Figure 4.9.6.11 Fatigue stress on the shaft. Solid Works

4.9.7 Belt selection

As expressed by SuperBrix S.A., their main conveyor belt provider is Icobandas S.A. The specific product line that is used for bucket elevators is one specialized for vertical conveying, called Icobandas ENL. The manufacturer affirms that these belts have excellent characteristics of flexibility and resistance [33].

It is necessary to check that the working load of the elevator is less or equal than the working load that the band can manage. For this, the working load is calculated as it follows.

$$T_{Work} = \frac{T_{1,r}}{w_B}$$

Where w_B is the width of the belt equal to the width of the bucket plus one inch as recommended in the literature.

$$T_{Work} = \frac{630{,}94\ \text{N} * \frac{1\ \text{lb}}{4{,}45\ \text{N}}}{6\ \text{in}}$$

$$T_{Work} = 23{,}63\ {}^{\text{lb}}/_{\text{in}}$$

The working load has a small value, this due to it is used in a testing bench and will not be subjected to major loads. The belt is chosen from using the next figure.

CARACTERISTICA	UNIDAD	icobandas ENL											
Tipo		168	252	336	420	220	330	440	550	280	420	560	700
Número de lonas		2	3	4	5	2	3	4	5	2	3	4	5
Espesor cojines	Pulgadas	1/16	1/16	1/16	1/16	1/16	1/16	1/16	1/16	5/64	5/64	5/64	5/64
Espesor total	mm	2,4	3,8	5,2	6,6	2,4	3,8	5,2	6,6	3,4	5,3	7,0	8,7
Peso	g/pulg/m	74	120	171	233	74	123	178	233	92	153	213	273
Carga de trabajo	lb/pulg	168	252	336	420	220	330	440	550	280	420	560	700
Carga de rotura	lb/pulg	1680	2520	3360	4200	2200	3300	4400	5500	2800	4200	5600	7000

Figure 5-16. Icobandas ENL catalog [33].

The belt used is the Icobandas ENL Type 168 with 2 plies that has a greater working load than the one calculated before.

4.10 LIST OF SPECIFICATIONS

Design Specifications: Rice bucket elevator testing bench.				
Concept	**Proposed by**	**R/D**	**Requirements**	**Target value**
Function	E	R	Transmit power from the engine to the drive pulley shaft.	23:1 Transmission
	C	R	Allow rice elevation from floor to head.	Minimum 8 buckets.
	E	R	Allow speed variation of the pulley.	Between 30% above and below of 60 rpm.
	E	R	Belt speed.	3,5 $\frac{m}{s}$
Dimensions	C	R	Bucket size	5 in x 4 in
	C	R	Head pulley diameter	41 cm
	E	R	Spacing between buckets	30 cm
	C	D	Elevator height	87,5 cm
Performance	C	D	Operational time	As required by the client
	C	D	Life cycle	5 years
Energy Source	C+E	R	Actioned by an AC motor placed in the upper pulley.	P > ¼ hp
Materials	C+E	R	Wear and corrosion resistant.	
	C+E	D	No hazard to the grain chemical integrity.	

Table 4.10.1. List of Specifications.

4.11 BILL OF MATERIALS

Item	Reference number	Quantity	Justification	Source
1	AC Motor R17DRS80M4/TF	1	Gearmotor to provide torque	SEW EURODRIVE
2	ANSI 50 GY50A1 Chain	1,5 m	Connector chain between gearmotor and sprocket	RENOLD CHAINS
3	50A19 20UF82 Sprocket	2	Verified sprocket	TSUBAKI
4	Square Flanged Bearing FYK30TF	4	Housing and shaft bearings	SKF
5	B-LOC Bushing B106 32 mm	4	Coupling between shaft and pulleys	FENNER DRIVES
6	ENL Belt Type 168 2 Plies 6 in Width	3 m	Conveyor belt	ICOBANDAS
7	Heavy Duty CC-HD 5 in x 4 in Bucket	10	Buckets to transport material	TAPCO
8	2HP 230V VFD AC Drive CFW100073SDPLZ	1	VFD to vary angular velocity	WEG
9	PM-410 Multi Grain Moisture Tester	1	Required for testing protocol	KETT
10	Industrial Counting Scale	1	Required for testing protocol	ULINE
11	Galvanized steel sheets	50 kg	Structure of the elevator	CENTRAL DE ACEROS
12	A36 Steel	21,4 kg	Structure of the elevator	CENTRAL DE ACEROS
13	Perforated sieve set	1	Required for testing protocol	HUMBOLDT MFG

Table 4.11.1. Detailed bill of materials.

4.12 BUDGET EXPENDITURE

In this section, the costs of the different resources needed to accomplish the project will be detailed. First, the detailed cost of all the equipment will be shown in the *table 4.12.1*

Equipment			
Component	**Quantity**	**Cost**	**Total**
SEW Eurodrive AC Motor R17DRS80M4/TF	1	$650.00	$650.00
Renold Chain ANSI 50 GY50A1	1.5 m	$116.09/m	$174.14
Tsubaki Sprocket 50A19 20UF82	2	$ 38.20	$76.40
SKF Square Flanged Bearing FYK30TF	4	$54.20	$216.80
B-LOC Bushing B106 32 mm	4	$35.72	$142.88
Icobandas ENL Type 168 2 Plies 6 in Width	3 m	$27.00/m	$81.00
Tapco Bucket Heavy Duty CC-HD 5 in x 4 in	10	$2.18	$21.80
Grain Moisture Tester	1	$645.00	$645.00
Uline Industrial Counting Scale	1	$549.00	$549.00
Perforated sieve set	1	$182.00	$182.00
230V WEG VFD AC Drive CFW100073SDPLZ	1	$316.99	$316.99
Final cost			**$3,056.01**

Table 4.12.1. Equipment cost.

Table 4.12.2 shows the required materials to manufacture a great portion of the elevator body, such as the sheets and the structural components that support it.

Material & Supplies			
	Quantity	**Cost**	**Total**
Grainger Approved Centerless Round AISI 1045 1¼ in	1.28 ft	$48.40/3 ft	$20.65
Galvanized Steel Sheet	50 kg	$1.37/kg	$68.50
A36 Steel 1/8 in	21.4 kg	$0.9/kg	$19.26
Final cost			**$108.41**

Table 4.12.2. Material and supplies cost.

And finally, a pricing of all the labor and assembly work that must be done to get all the parts in their required form and the elevator together, all the bolts are included in this price.

Labor & Assembly		
Item	**Description**	**Cost**
1	Machining for upper and lower 1045 shafts according to blueprints	$83.13
2	Folding according to C-Profiles blueprints in 3mm sheet with perforation	$50.23
3	Manufacturing, cutting, machining of metal sheet for upper and down pulley according blueprints and assembling with MIG welding	$308.28
4	Manufacturing of Gear-motor's support with tensioning slide	$58.88
5	Frame manufacturing with 1 ½" x ¼" angle according blueprints	$332.53
6	Cut and fold of 16-gauge galvanized metal sheets according blueprints for assembly	$273.64
7	Assembly, bolted, and riveted of all parts	$329.06
SUBTOTAL		$1,435.75
TAXES 19%		$272.79
TOTAL		**$1,708.54**

Table 4.12.3. Labor and assembly cost.

Item	**Final Cost**
Material & Supplies	$108.41
Equipment	$3,056.01
Labor & Assembly	$1,708.54
Sub-total	$4,872.96
Uncertainty	10%
Total project	**$5,360.26**

Table 4.12.4. Total project cost.

Adding all the costs, the final estimated value is $5,011.57 dollars. This cost doesn’t include the price concerning to the scientific labor of the engineers working on it.

4.13 FINAL DESIGN

After all calculations, the figure 4.13.1 shows the final design with all the components installed.

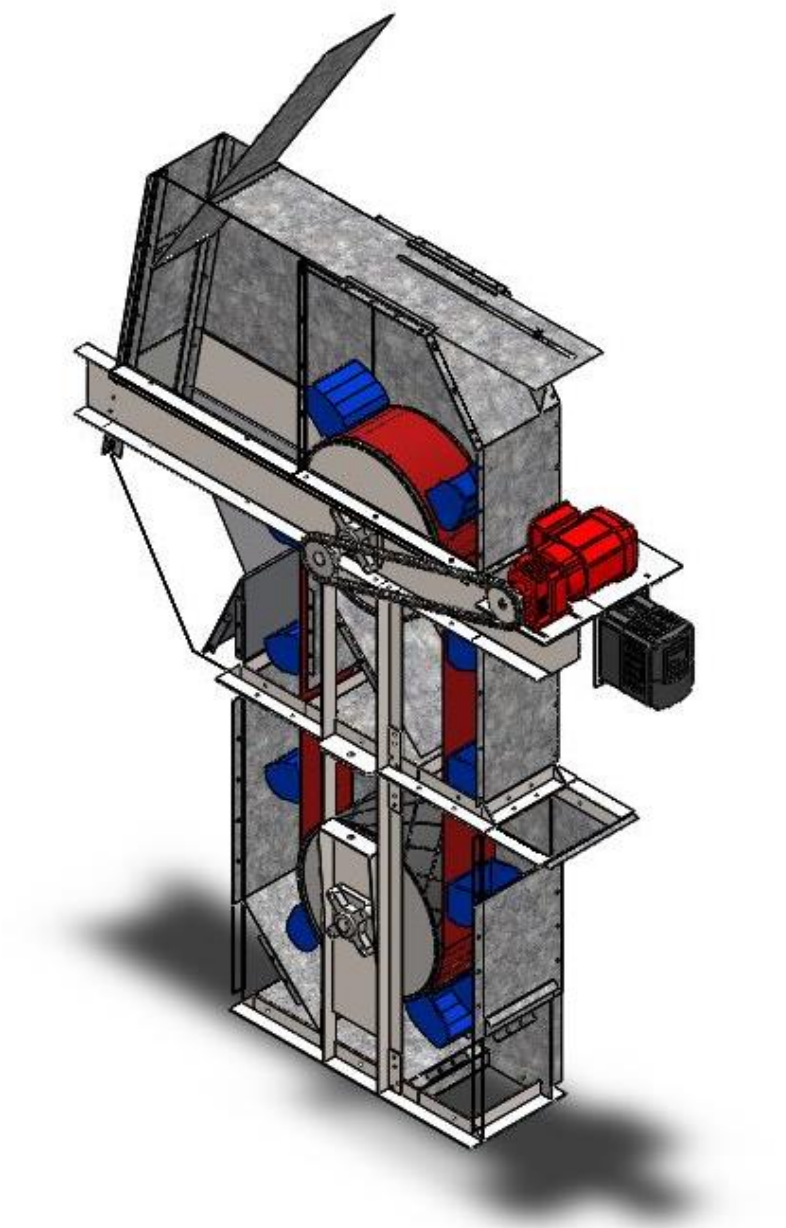


Figure 4.13.1. Final design. Solid Works

5. TESTING PROTOCOL

The purpose of this document is to provide information pertinent to the testing and analysis of rice damage. It includes an overview of rice properties and variables to be tested, a detailed testing procedure, and recommendations for data analysis. In conjunction with the mechanical test bench, this testing protocol will aid SuperBrix in making well-informed design decisions in making detailed and effective recommendations to clients.

5.1 PROTOCOL

The outlined testing protocol is a step by step, easy to follow, repeatable procedure that can be followed by a user with limited knowledge and experience with rice processing.

It is recommended that certain equipment be utilized for the successful implementation of the protocol. One of the recommended pieces of equipment is a perforated sieve composed of multiple mesh screens of different perforation diameters, shown in *figure 5.1.1*. To accommodate for the testing of all types of rice, the following round perforation sizes are recommended (in order of decreasing size): 4.7mm, 3.0mm, 2.5mm, and 1.4mm. The sieves will separate the damaged rice based on size, specifically into groups of large, medium, and small broken grains and brewers, to provide an overall profile of the damaged rice. Brewers are broken grains smaller than 1.4mm in length. A laboratory scale like the one in *figure 5.1.2*, used to measure the mass of rice collected in each sieve, is also necessary for the proper implementation of the protocol [21,22].

Figure 5.1.1. Perforated sieve set [22].

Figure 5.1.2. Laboratory scale [23]

To establish moisture content as a control variable, moisture readings should be taken prior to test bench operation. A laboratory moisture tester, such as the one in *figure 5.1.3,* accurately assesses the moisture content of the sample before testing. Variation in moisture content above or below the optimum value of 14% can greatly affect damage results [21].

Figure 5.1.3. Moisture Tester [24]

It is recommended that all tests for a single variable be run on the same day under the same environmental conditions to ensure that any change in damage can be attributed solely to the changed variable. The initial conditions of the rice must be recorded before completing the tests.

1. Establish which variable/parameter is being tested and which will be held constant
2. Obtain two 150-200g samples from the bench sample to test the initial conditions
3. Place one sample in the moisture tester machine and record reading

4. Place the other sample in perforated sieve set or indented plate
5. If using a sieve, shake the contents back and forth ten times
6. Separate the layers of the sieve
7. Separately place the contents of each layer of the sieve on the laboratory scale and record mass of each in order of decreasing perforation diameter
8. Change the test variable (i.e. change the angle of the head or the spacing of the buckets)
9. Specify number of cycles the bench sample will be exposed to
10. Load test bench with the entire sample and run it for the specified number of cycles
11. Obtain two 150-200g samples. Repeat the procedures from initial condition testing and record results

An excel spreadsheet is provided for recording the testing data and includes graphs for preliminary data analysis. The spreadsheet requires the operator to run three trials of the protocol, with additional samples taken prior to and after testing. A sample of the spreadsheet is found below in *figure 5.1.4*.

Technician		**TESTING RECORDS FOR TEST BENCH**				
Date						
Grain Type		**Sample**	**Trial 1**	**Trial 2**	**Trial 3**	**Trial Avg.**
		A				
Initial Testing	Weight (g)		–	–	–	–
	Large brokens (g)	–				0
	Medium brokens (g)	–				0
	Small brokens (g)	–				0
	Moisture Content (%)		–	–	–	–
	Temperature (°C)		–	–	–	–
	Velocity (Hz)		–	–	–	–
	Head Angle (deg)		–	–	–	–
		B				
Final Testing	Weight (g)		–	–	–	–
	Large brokens (g)	–				0
	Medium brokens (g)	–				0
	Small brokens (g)	–				0

Figure 5.1.4. Screenshot of Excel file for recording data.

5.2 GRADING OF MILLED RICE

Top grade of rice has the following characteristics (by sample):

- 14% Moisture Content (MC)
- 95% Purity
- ≤ 7% damaged kernels
- Free from infestation

Moisture content is an important parameter in rice processing. Quantities with measurements above 14% are generally more prone to mold growth and spoilage. Measurements below 14% indicate a higher rate of crack and fissure development and an overall higher rate of damage among rice kernels.

The amount of impurities/damaged grains is a determinant of quality in rice processing. Damage is graded based on extent and size of broken particles, as well as the presence of fissures or cracks in the grains. Large brokens are grains that are 4/5 to one half the length of the average unbroken grain. Medium brokens are between one half and 2/5 the length of the average grain. Small brokens are pieces smaller than the length of the average grain. Brewers are the smallest type of recordable grain and are typically small enough to pass through a sieve with round perforations 1.4 mm in diameter.

Figure 5.2.1 outlines the standards provided by the Food and Agriculture Organization of the United Nations (FAO) and *figure 5.2.2* depicts the sizes of brokens.

GRADING FACTORS	**GRADE PREMIUM: 1: 2: 3**
Head Rice (Min %)	95.00:80.00:65.00:50.00
Large Brokens (Max %)	3.00: 10.00: 10.00:20.00
Broken Other than Large Brokens (Max %)	1.90: 9.75:24.00:29.00
Brewers (Max %)	0.10: 0.25: 0.50: 1.00
Defectives:	
Damaged Kernels (Max %)	- : 0.25:0.50: 2.00
Discolored Kernels (Max %)	0.50: 2.00: 4.00: 8.00
Chalky & Immature Kernels (Max %)	2.00: 5.00: 10.00: 15.00
Contrasting Types (Max %)	3.00: 6.00: 10.00: 18.00
Red Kernels (Max %)	- : 0.25: 0.50: 2.00
Red Streaked Kernels (Max %)	1.00: 3.00: 5.00: 10.00
Foreign Matter (Max%)	- : 0.10: 0.20: 0.50
Paddy (Max. no. per 1000 grams)	1 : 8 :10 :15
Moisture Content (Max %)	14.00: 14.00: 14.00: 14.00

Figure 5.2.1: FAO Grade Requirements for Milled Rice [21].

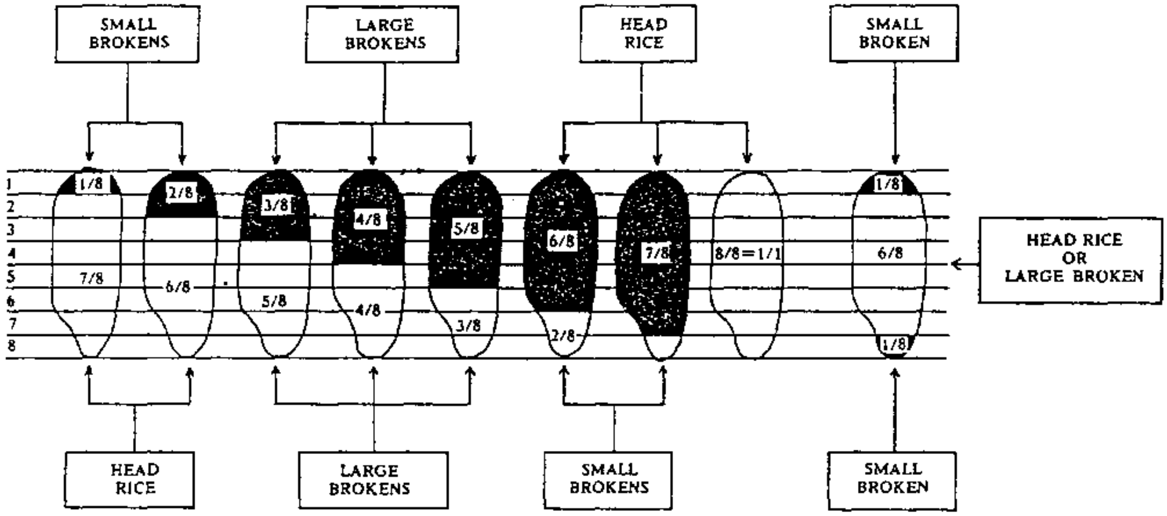


Figure 5.2.2: Diagram of Damage Specifications for Milled Rice [21].

5.3 JUSTIFICATION OF PROTOCOL

The purpose of this document is to provide information pertinent to the testing and analysis of rice damage. It includes an overview of rice properties and variables to be tested, a detailed testing procedure, and recommendations for data analysis. ISO 7301 and Codex 198 standards were consulted in the development of the testing procedures. In conjunction with the mechanical test bench, this testing protocol will aid SuperBrix in making well-informed design decisions in making detailed and effective recommendations to clients.

6. CONCLUSIONS AND RECOMENDATIONS

The mechanical design carried out, took into account geometric parameters used previously in the manufacture of the elevators of the client, the conceptual and basic design also allowed to evaluate these earlier used geometries. The mechanical design led to a functional alternative that would allow evaluating the variables established by the client.

From the study it was found that the performance of the equipment and the final quality of the rice depends on the geometrical parameters and operating parameters. The **operating velocity** should be the first consideration, as well as the diameter of the pulley, these two factors will determine the kinetical energy of the rice, which will be traduced in the impact force. The **head geometry** is also important, especially if the operating velocities are high, in this case, the head will be the impact surface that will reflects and damage the grain. As a prediction, the parabolical or curved head geometry will perform better due to the parabolic trajectory of the grain. The **geometry of the bucket** influences the trajectories given that the forces present throughout the launching phenomenon, takes into account the exit angle of the bucket’s outer wall. The **space between buckets** will influence the capacity and the power required, but probably not the damage caused to the grain.

The need to establish measurable variables in the process such as rice quality represented a fundamental part in the evaluation of possible configurations. The testing protocol included, for its part, an efficient and viable way to evaluate the quality of the rice and make comparisons in future tests. The selection of components, budget, manufacturing CAD files and the testing protocol are the final deliverables of this work.

As a continuation of this project, the implementation of the testing protocol should be completed by SuperBrix. The company has also the responsibility to construct the test bench. The data acquisition portion of the research should be completed either by SuperBrix staff or Universidad del Norte students. The analysis of the tests results and the implementations of the findings in the current buckets elevators design is also a responsibility of the Superbrix mechanical design team.

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This would not have been possible without my family, my main source of energy and love and my biggest support during all my life.

Finally, I am grateful to University of Illinois, ICAI, Universidad del Norte and Superbrix for giving me all the facilities and knowledge necessary for the completion of this project.

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9. APPENDICES

9.1 PROJECT STATUS REPORTS (PSR)

PSR #1

Group: Parce-rroz

Client Contacts: Professor Hugo Caballero- caballeroh@uninorte.edu.co

Period: January 22, 2018 - February 2, 2018

Progress for the Period:

- Reached out to Professor Caballero- still waiting for UniNorte to form the group we will be working with. Team meeting- completed a draft of the project charter. We are missing a lot of information
- Researched Superbrix International S.A.
- Company based in Barranquilla, Colombia that designs and manufactures equipment and facilities for the rice milling and processing industries. They also are involved in grain and seed conditioning and storage, cereal fractionation, bio-fuels production and port bulk grain handling systems

Goals for the Upcoming Period:

- Make contact with the UniNorte group
- Establish communication and document naming protocol
- Team dinner

Project Milestones:

Project Charter Final Draft- Feb 18

Potential Problems:

Universidad del Norte began their semester later than UIUC, so we were not able to make contact immediately. This may set us back a week or two.

PSR #2 (week 4)

Group: Parce-rroz

Client Contacts: Professor Hugo Caballero- caballeroh@uninorte.edu.co

Period: February 3, 2018 - February 11, 2018

Progress for the Period:

- Met the UniNorte team, we will be working with four Mechanical Engineering students
- Had a skype meeting with UniNorte group and Professor Caballero
  - Found out a bit more information on the project- they will be meeting with the client on Thursday and will have more information after the meeting
  - Established contact people- German from their team and Ariel and Jose from our team
  - They have asked us to do research on the mechanical properties of rice for the time being, so we have some information to work with after the client meeting
  - Seems that they will need us more for ag-related information than mechanical ideas
  - They will try to work with our deadlines since we got a bit of a late start
- Came up with a team logo- the UniNorte group really liked our idea
- Spoke with Dr. Grift- since our side of the project is not mechanical, he can't help much
  - Gave us a book with mechanical property information of various foods
  - Has a former student who we can contact for help if necessary

Goals for the Upcoming Period:

- Provide UniNorte team with information about the mechanical properties and processing of paddy rice
- Contact Professor Rausch or Professor Singh- they may have more information for us about food and grain processing
- Meet with the team over Skype to hear about client meeting and establish next steps

Project Milestones:

- UniNorte team meets with SuperBrix- Thursday, Feb 15
- Weekly Skype meeting with UniNorte team- Friday, Feb 16
- Project Charter Final Draft- Feb 18

Potential Problems:

- We are worried that the project charter will not be completed on time due to the client meeting being delayed
- The balance of work between us and the UniNorte team is a bit unclear, but will likely become more apparent as the project develops

PSR #3 (week 5)

Group: Parce-rroz

Client Contacts: Professor Hugo Caballero- caballeroh@uninorte.edu.co

Period: February 11, 2018 - February 18, 2018

Progress for the Period:

- Met with UniNorte team to discuss questions for them to ask the client during their meeting
- UniNorte team had a meeting with the client. They recorded video and audio of explanations by the SuperBrix design team and asked the questions that we discussed prior to their visit
- Met with UniNorte team after the client meeting to hear about the visit to SuperBrix's facility
- Came up with some clear objectives for each group:
- UniNorte team will begin mechanical design. We hope to have a preliminary design within a month
- We will research the properties and processes of rice to find out at what point rice is most susceptible to damage
- Our job will also be to ensure that the rice is arriving at the bucket elevator at the ideal conditions for reducing breakage
- With more clear objectives, we have begun to look through documentation on bucket elevators as well as research rice properties and processing

Goals for the Upcoming Period:

- Provide UniNorte team with information about the mechanical properties and processing of paddy rice
- Contact Professor Rausch or Professor Singh- they may have more information for us about food and grain processing
- Prepare for our first presentation of the semester
- We would like to contact the client directly to ensure that no information has been lost
- Contrast our goal with the goal of the client, and comment new ideas

Project Milestones:

- Project Charter Final Draft- Feb 18 (we may not have it 100% completed by the deadline)
- Presentation #1- Feb 21-22
- Research and send rice property information to UniNorte team by Friday, Feb 23
- Completed mechanical design- 3/16

Potential Problems:

- We are worried that the project charter will not be completed on time due to the client meeting being delayed
- Time frame of the mechanical design- may take longer than we expect

PSR #4 (week 6)

Group: Parce-rroz

Client Contacts: Professor Hugo Caballero- caballeroh@uninorte.edu.co

Period: February 18, 2018 - February 25, 2018

Progress for the Period:

- Presented our project to the class and received feedback on our presentation
- Some students found the divide between us and UniNorte to be a bit unclear, so we will try to elaborate on the relationship in the next presentation
- Had a meeting with the client and UniNorte team
- Meeting was recorded for the absent members to listen to later
- Client seemed pleased with our proposal to develop a test bench and a protocol for testing various design changes and their effect on the rice during processing
- We have divided the action items of the project into four parts to be researched/worked on
- Part 1- Process of rice (researching the process and properties)
- Part 2- Existing rice testing protocol (how is it currently tested for quality)
- Part 3- Establish a plan and deadline, nail down a budget, and organize documentation
- Part 4- Hypothesis, mechanical design, and expected results

Goals for the Upcoming Period:

- Each team member will pick one of the parts listed above to work on this week
- We will meet later in the week to discuss our findings and to have our weekly skype call with the UniNorte team

Project Milestones:

- Each member report findings on parts 1-4 by 3/4
- Completed mechanical design- 3/16
- Presentation #2- 3/29-3/30
- Final report requirements- 4/4

Potential Problems:

- It is possible that we are doing more research than is required to successfully complete this project
- Better to be prepared and knowledgeable, but we could also be wasting time researching things that will have no bearing on the success of the final project

PSR #5 (week 7)

Group: Parce-rroz

Client Contacts: Professor Hugo Caballero- caballeroh@uninorte.edu.co

Period: February 25, 2018 - March 4, 2018

Progress for the Period:

- We have divided the action items of the project into four parts to be continuously researched/worked on:
- Part 1- Process of rice (researching the process and properties)
- Found some useful graphics outlining typical rice processing
- Researched quantity and locations of bucket elevators in processing plants
- Part 2- Existing rice testing protocol (how is it currently tested for quality)
- Part 3- Establish a plan and deadlines, nail down a budget, and organize documentation
- Part 4- Hypothesis, mechanical design, and expected results
- Individually worked on each part
- Met with Uninorte to discuss the mechanical problems and design
- Established a consistent way to cite our sources during the research process

Goals for the Upcoming Period:

- Further research and develop each part listed above
- Update the Gantt Chart
- Agree on specifications of the mechanical design
- Create a budget

Project Milestones:

- Completed mechanical design- 3/16
- New draft of project charter with current information- 3/16
- Presentation #2- 3/29-3/30
- Final report requirements- 4/4

Potential Problems:

- Running out of time- as we mentioned in our presentation, communication can take longer for our team because we are working with another team of students as well as with the client
- Problems related with ideal measures and cost-efficiency

PSR #6 (week 8)

Group: Parce-rroz

Client Contacts: Professor Hugo Caballero- caballeroh@uninorte.edu.co

Period: March 4, 2018 - March 11, 2018

Progress for the Period:

- We have divided the action items of the project into four parts to be continuously researched/worked on:
- Part 1- Process of rice (researching the process and properties)
- Found some useful graphics outlining typical rice processing
- Researched quantity and locations of bucket elevators in processing plants
- Part 2- Existing rice testing protocol (how is it currently tested for quality)
- Part 3- Establish a plan and deadlines, nail down a budget, and organize documentation
- Part 4- Hypothesis, mechanical design, and expected results
- Helped the UniNorte team with designing the parabolic trajectory of the grain.
- Studied the possible design of an adaptable bucket head
- Had a group meeting
- Worked on researching testing protocol and rice properties
- Continued working on Project Charter
- Looked through all of the material that has been uploaded by the UniNorte team, including their assignment submissions

Goals for the Upcoming Period:

- Further research and develop each part listed above
- Update the Gantt Chart
- Agree on specifications of the mechanical design
- Create a budget

Project Milestones:

- Completed mechanical design- 3/16
- New draft of project charter with current information- 3/16
- Presentation #2- 3/29-3/30
- Final report requirements- 4/4

Potential Problems:

- Running out of time- as we mentioned in our presentation, communication can take longer for our team because we are working with another team of students as well as with the client
- Maintaining steady communication with UniNorte team throughout the semester
- Our ability to predict the critical variables of the design

Week 9 PSR

Group: Parce-rroz

Client Contacts: Professor Hugo Caballero- caballeroh@uninorte.edu.co

Period: March 11, 2018 - March 18, 2018

Progress for the Period:

- We have continued to work on the following parts:
- Part 1- Process of rice (researching the process and properties)
- Found some useful graphics outlining typical rice processing
- Researched quantity and locations of bucket elevators in processing plants
- Part 2- Existing rice testing protocol (how is it currently tested for quality)
- Part 3- Establish a plan and deadlines, nail down a budget, and organize documentation
- Part 4- Hypothesis, mechanical design, and expected results
- Helped the UniNorte team design 3 possible designs (Jose)
- Further considered adaptable elevator head

Goals for the Upcoming Period (after spring break):

- Select a design from our three possibilities
- Update the schedule
- Create a specific budget
- Prepare for presentation #2

Project Milestones:

- Presentation #2- 3/29-3/30
- Final project executive summary- April 15
- Trade show- April 19
- Final client meeting- unknown?

Potential Problems:

- Running out of time- as we mentioned in our presentation, communication can take longer for our team because we are working with another team of students as well as with the client
- We will be on spring break, then they will be on break. That is two weeks with only half of the group working!
- How will we meet with the client?

Week 11 PSR

Group: Parce-rroz

Client Contacts: Professor Hugo Caballero- caballeroh@uninorte.edu.co

Period: March 25, 2018- April 1, 2018

Progress for the Period:

- We have continued working on the following:
- Part 1- Process of rice (researching the process and properties)
- Found some useful graphics outlining typical rice processing
- Researched quantity and locations of bucket elevators in processing plants and created an easy to understand diagram
- Part 2- Existing rice testing protocol (how is it currently tested for quality)
- Also researched the structure of a rice grain and properties like moisture content
- Part 3- Establish a plan and deadlines, nail down a budget, and organize documentation
- Budget is complete, but labor costs need to be added
- Part 4- Hypothesis, mechanical design, and expected results
- UniNorte has completed 3 designs for a bucket elevator
- We have decided on and created a budget for what we thought to be the best design
- Finished presentation 2 and got positive feedback

Goals for the Upcoming Period:

- Further research and develop each part listed above
- Add labor costs to budget
- Begin developing testing protocol to accompany selected design
- Begin safety analysis

Project Milestones:

- Outline testing protocol- April 7
- Final project executive summary- April 15
- Trade show- April 19
- 4/25-4/26- Presentation 3
- Client presentation- unknown

Potential Problems:

- Running out of time-communication can take longer for our team because we are working with another team of students as well as with the client
- Maintaining steady communication with UniNorte team throughout the semester
- Spring break= 2 weeks with not much being done!
- Setting up the client meeting- logistical issues

Week 12 PSR

Group: Parce-rroz

Client Contacts: Professor Hugo Caballero- caballeroh@uninorte.edu.co

Period: April 1, 2018 - April 8, 2018

Progress for the Period:

- We have continued working on the following:
- Part 1- Process of rice (researching the process and properties)
- Part 2- Existing rice testing protocol (how is it currently tested for quality)
- Part 3- Establish a plan and deadlines, nail down a budget, and organize documentation
- Budget is complete, but labor costs need to be added
- Part 4- Hypothesis, mechanical design, and expected results
- We have decided on and created a budget for what we thought to be the best design
- Researching health and safety information- HDRS
- Did some research on rice pricing and the parameters which affect it
- Began working on final report draft

Goals for the Upcoming Period:

- Add labor costs to budget
- Develop testing protocol to accompany selected design
- Begin safety analysis
- Continue writing final report

Project Milestones:

- Final project executive summary- April 15
- Trade show- April 19
- 4/25-4/26- Presentation 3
- Client presentation- unknown
- Final project draft- 5/6

Potential Problems:

- Running out of time-communication can take longer for our team because we are working with another team of students as well as with the client
- Setting up the client meeting- logistical issues

Week 14 PSR

Group: Parce-rroz

Client Contacts: Professor Hugo Caballero- caballeroh@uninorte.edu.co

Period: April 15, 2018- April 22, 2018

Progress for the Period:

- We have begun creating the protocol document which will include:
- Properties of rice
- Rice grain variables
- Detailed description of testing variables
- Geometry of the head, bucket shape, bucket spacing, and velocity
- Methods and materials
- Step by step testing procedure
- We have decided on a multi-layer sieve to separate and measure the percentages of certain sized broken grains
- Description of the grading of milled rice
- Justification of protocol
- Cite existing protocol and explain the reasoning behind the chosen procedure
- Excel spreadsheet for recording and analysis of data
- Recommendations for analysis of data
- Completed executive summary and table of contents
- Created trade show poster and presented

Goals for the Upcoming Period:

- Add labor costs to budget
- Complete protocol document and send to UniNorte team
- Skype meeting with UniNorte team
- Begin safety analysis
- Continue writing final report

Project Milestones:

- 4/25-4/26- Presentation 3
- Client presentation- unknown
- Final project draft- 5/6

Potential Problems:

Setting up the client meeting- logistical issues

9.2 SAFETY ANALYSIS HAZARD DISCOVERY RATING SYSTEM (HDRS)

ITEM NUMBER	HAZARD TYPE AND DESCRIPTION	HAZARD ANALYSIS		QUANTIFICATION				REMARKS OF THE DESIGN GROUP
		INJURY POTENTIAL	FACTORS CONTRIBUTING TO THE HAZARD	FREQ	VULN	SEVER	COMP#	
1.	Injury from contact with moving parts	Arms, head, legs damaged	Belt fail, bucket fail, low maintenance	3	4	5	60	Protect all moving parts
2.	Eye injury resulting from high-velocity, airborne particles	Vision lost	Operators inside the dangerous zone when working, belt fail	2	2	7	28	Use protections in the critical points (inlet and outlet)
3.	Dust explosion	Eyes damaged,	Accumulated dust in the machine Low maintenance Low humidity	1	3	3	9	Use explosion holes to reduce the pressure Eliminate the places where dust can be accumulated
4.	Electrical hazards	General electrocution	Bad maintenance Bad use of security protocols	1	7	6	42	Use all electrical protections possible

9.3 INITIAL BUDGET COMPARISON

The initial project budget is seen below in *table 9.3.1*. Most of it is comprised of physical components of the test bench such as pulleys, transmission belt, buckets and bearings. However, as our team did not build a physical model, there is almost no difference in budget from the initial test bench design.

Nonetheless, some extra costs were taken into consideration like how to test rice damage. Our components proposal for the data acquisition is seen on *table 9.3.2*. The breakdown of each is seen on the testing protocol section on the report.

COMPONENT	DESCRIPTION	QUANTITY	PRICE PER UNIT(US DOLLARS)	TOTAL COMPONENT PRICE ($)
Variable frequency drive	Kinco CV20-2S-0004G VFD	1	79	79
Belt pulleys	Congress Fixed Bore V-Belt 4in Pulley	1	17.35	17.35
Belt pulleys	Congress Fixed Bore V-Belt 3in Pulley	1	13.65	13.65
Belt pulleys	Congress Fixed Bore V-Belt 2in Pulley	1	11.45	11.45
Belt pulleys	Congress Fixed Bore V-Belt 1in Pulley	1	10.6	10.6
Transmission belt	Dayton 4L/A V-Belt	2	6.9	13.8
Buckets	Tapco High Density Polyethylene Elevator Buckets 5 x 4	10	50	500
Pulley bearings	Tritan 4-Bolt Flange Bearings	4	19.45	77.8
Shaft bearings	Dayton Pillow Block Bearings	4	23.35	93.4
Structure	Galvanized Steel	0.09	1500	135
TOTAL				$ 952.05

Table 9.3.1. Test bench detailed parts budget

COMPONENT	QUANTITY	PRICE PER UNIT(US DOLLARS)	TOTAL COMPONENT PRICE
Grain Moisture Tester	1	$645	$645
Uline Industrial Counting Scale	1	$549	$549
Perforated sieve set	1	$182	$182
TOTAL			$1,376

Table 9.3.2. Testing detailed parts budget

9.4 DRAWINGS OF THE SELECTED DESIGN

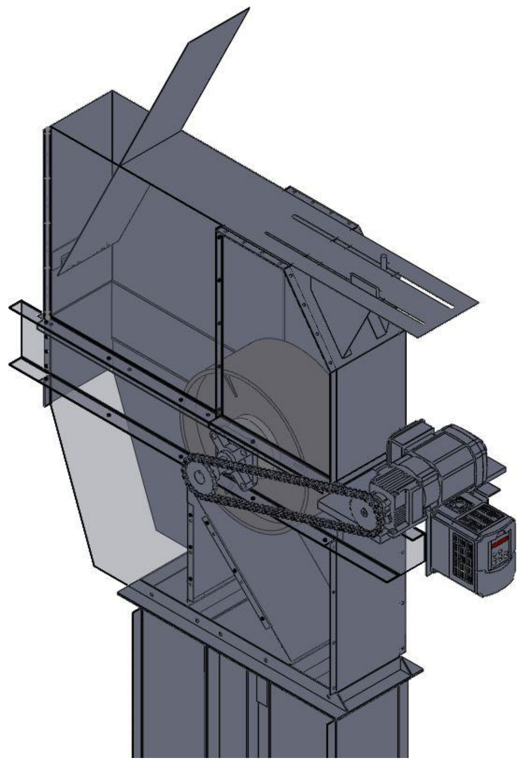


Figure 9.4.1. CAD image of the selected design. Head. (Solid Works)

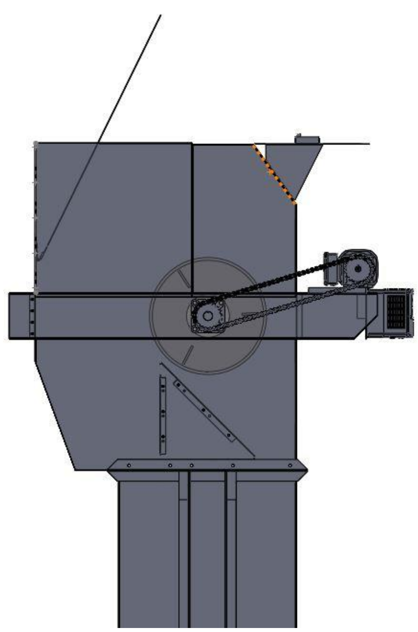


Figure 9.4.2. CAD image of the selected design. Side. (Solid Works)

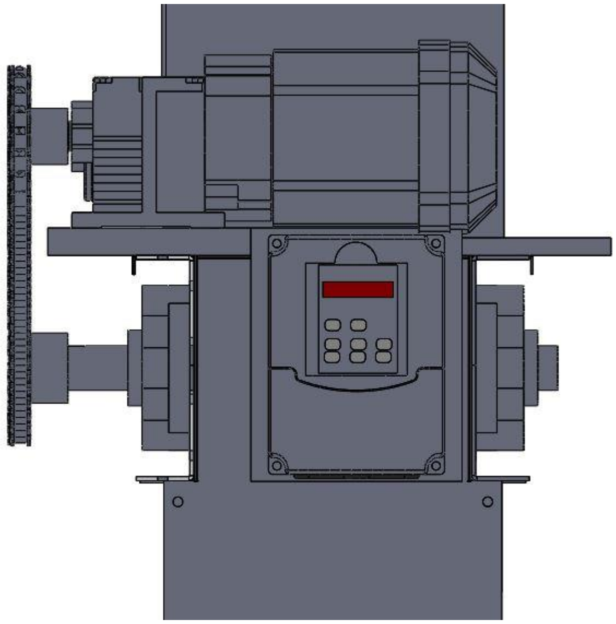


Figure 9.4.3. CAD image of the selected design. Motor and frequency variator (Solid Works).

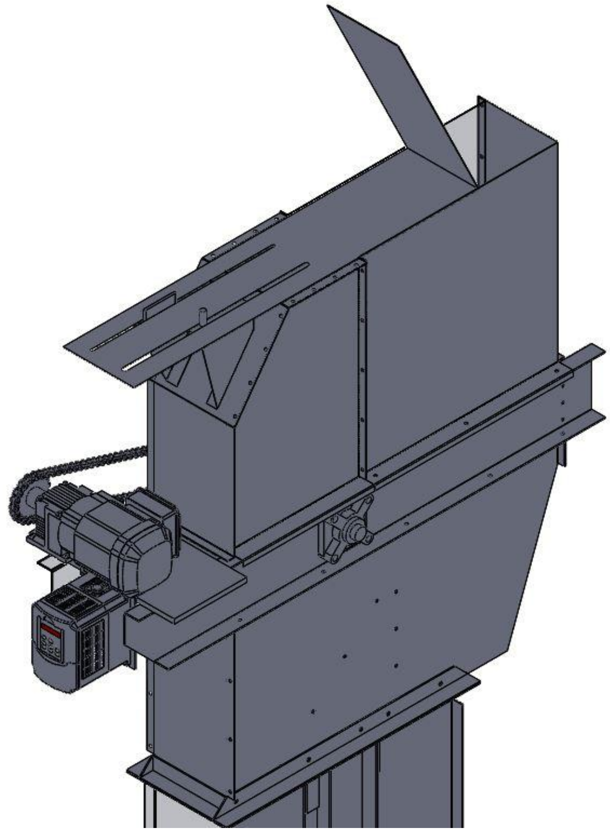


Figure 9.4.4. CAD image of the selected design. Back part. (Solid Works)

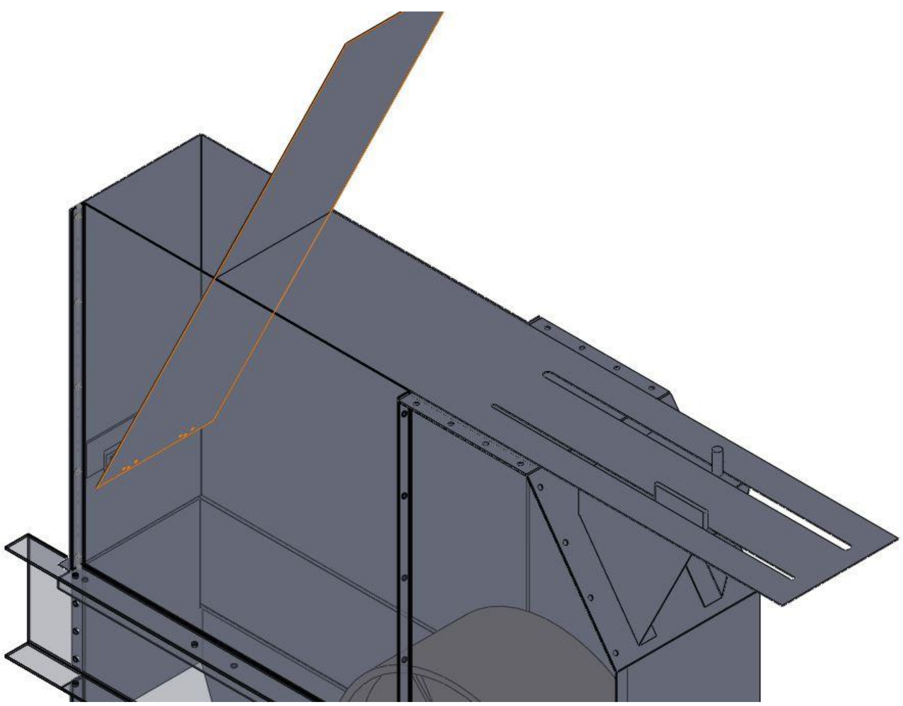


Figure 9.4.5. CAD image of the selected design. Rail guided detail. (Solid Works)

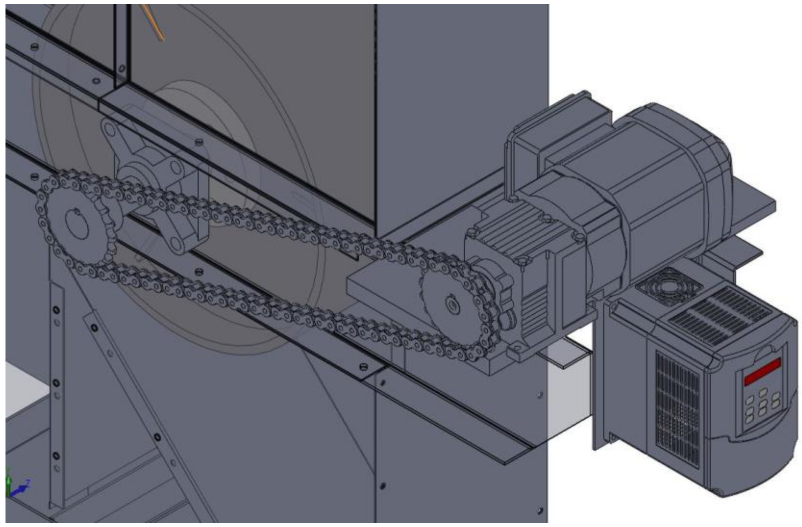
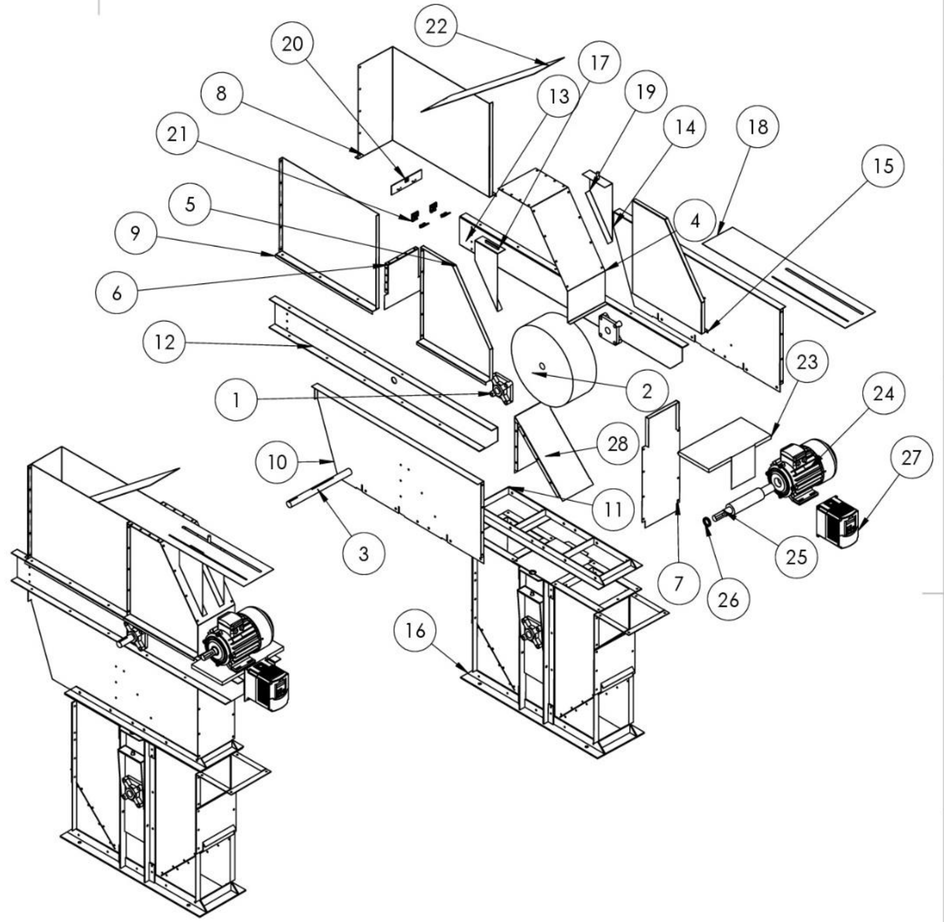


Figure 9.4.6. CAD image of the selected design. Transmission Chain. (Solid Works)

9.5 BLUEPRINTS

All the blueprints have an only illustrative purpose, They do not follow any drawing standards and they are not relevant for the project. Superbrix team will extract its own blueprints from the CAD files. Thus, the blueprint classification table is not relevant and was not added.

ITEM NO.	PART NUMBER	DESCRIPTION	Default/ QTY.
1	Drum shaft's Bearing		2
2	Top Drum		1
3	Drum Shaft		1
4	Top Cover A		1
5	Lateral Cover A		1
6	Lateral Cover C		1
7	Lateral Cover D		1
8	Lateral Cover E		1
9	Lateral Cover F		1
10	Lateral Cover G		1
11	Frame		1
12	Lateral Support A		1
13	Lateral Support B		1
14	Lateral Cover H		1
15	Lateral Cover B		1
16	BASE 5X4		1
17	Top Sheet A		1
18	Top Cover B		1
19	Top Sheet B		1
20	Sliding plate		1
21	Hinge		4
22	Top Cover C		1
23	Motor support plate		1
24	AC-MOTOR		1
25	AC MOTOR ROTOR		1
26	ISO 15 RBB - 1832 - 26,SI,NC,26_68		1
27	Frecuency Driver		1
28	Diverting Sheet		1



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FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

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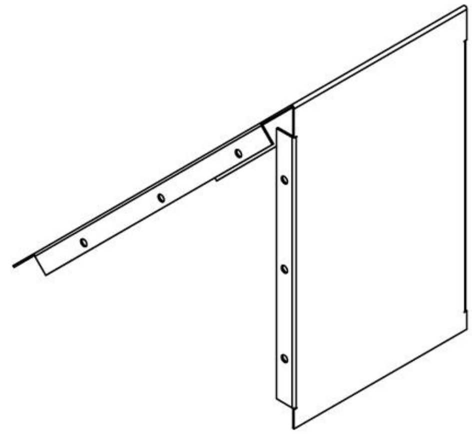
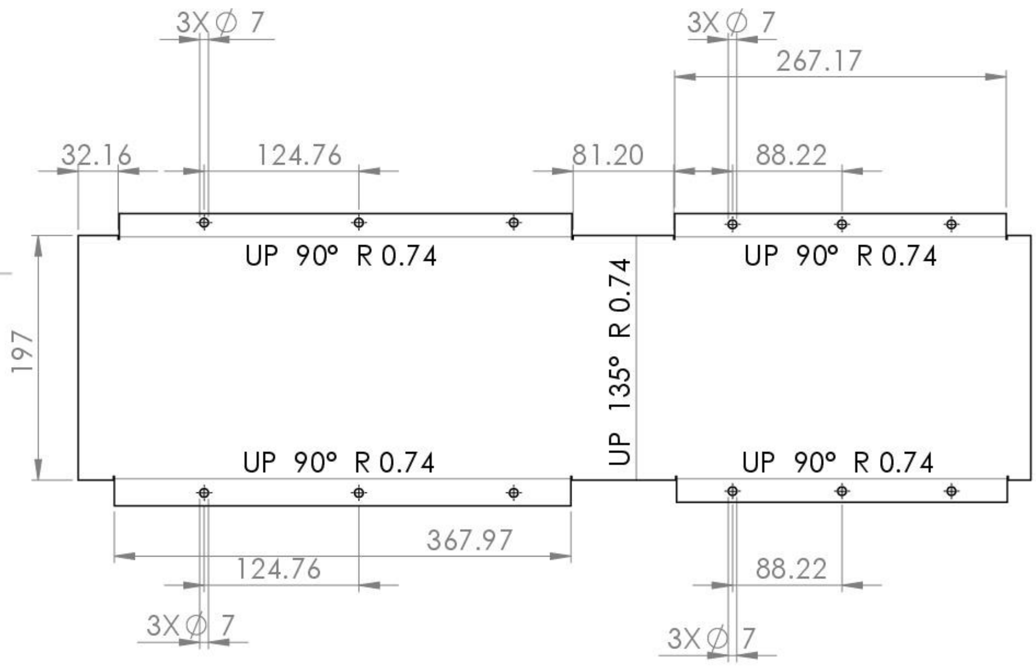
SHEET 1 OF 1





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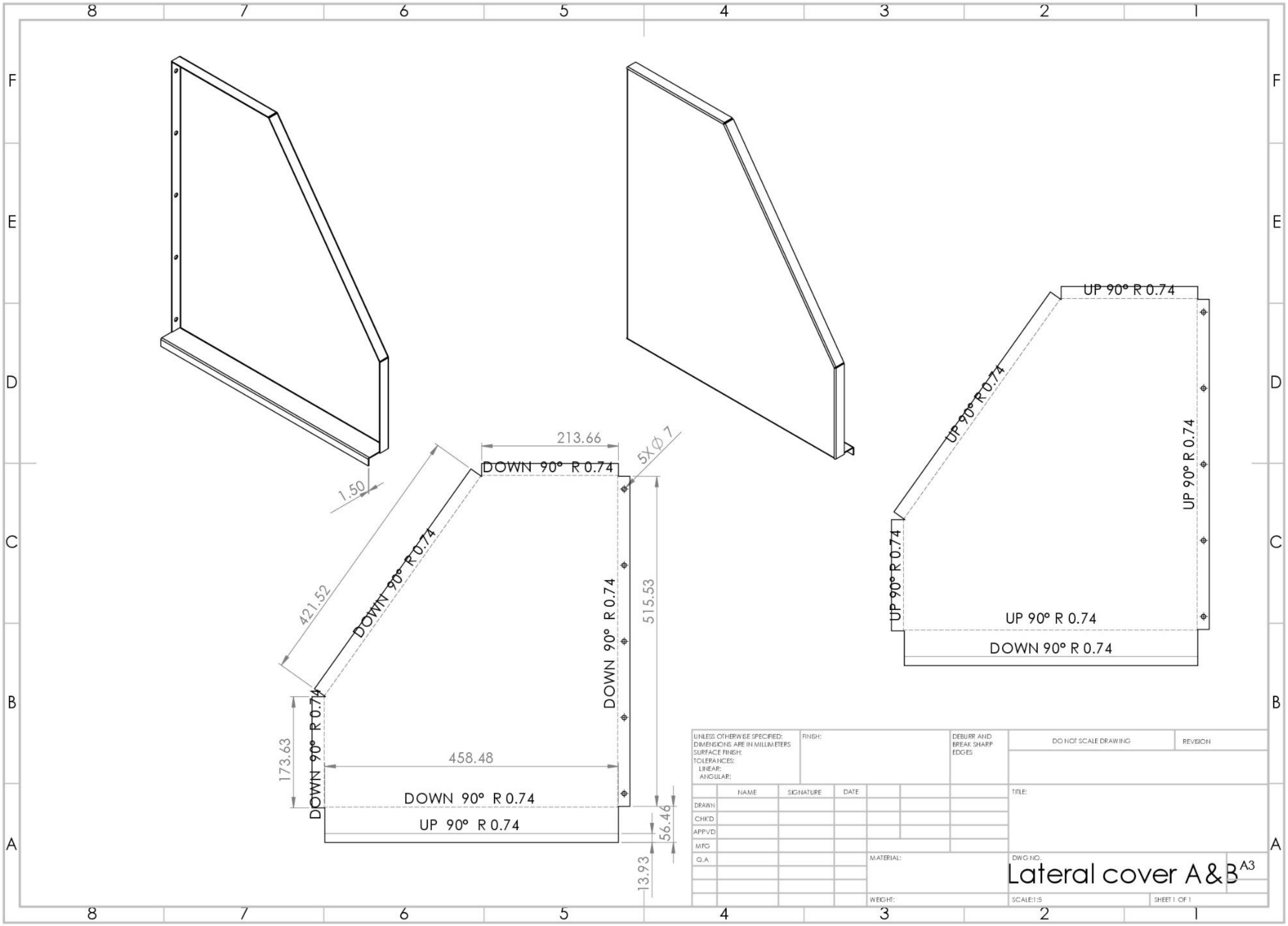
SHEET 1 OF 1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DOWN 90° R 0.74
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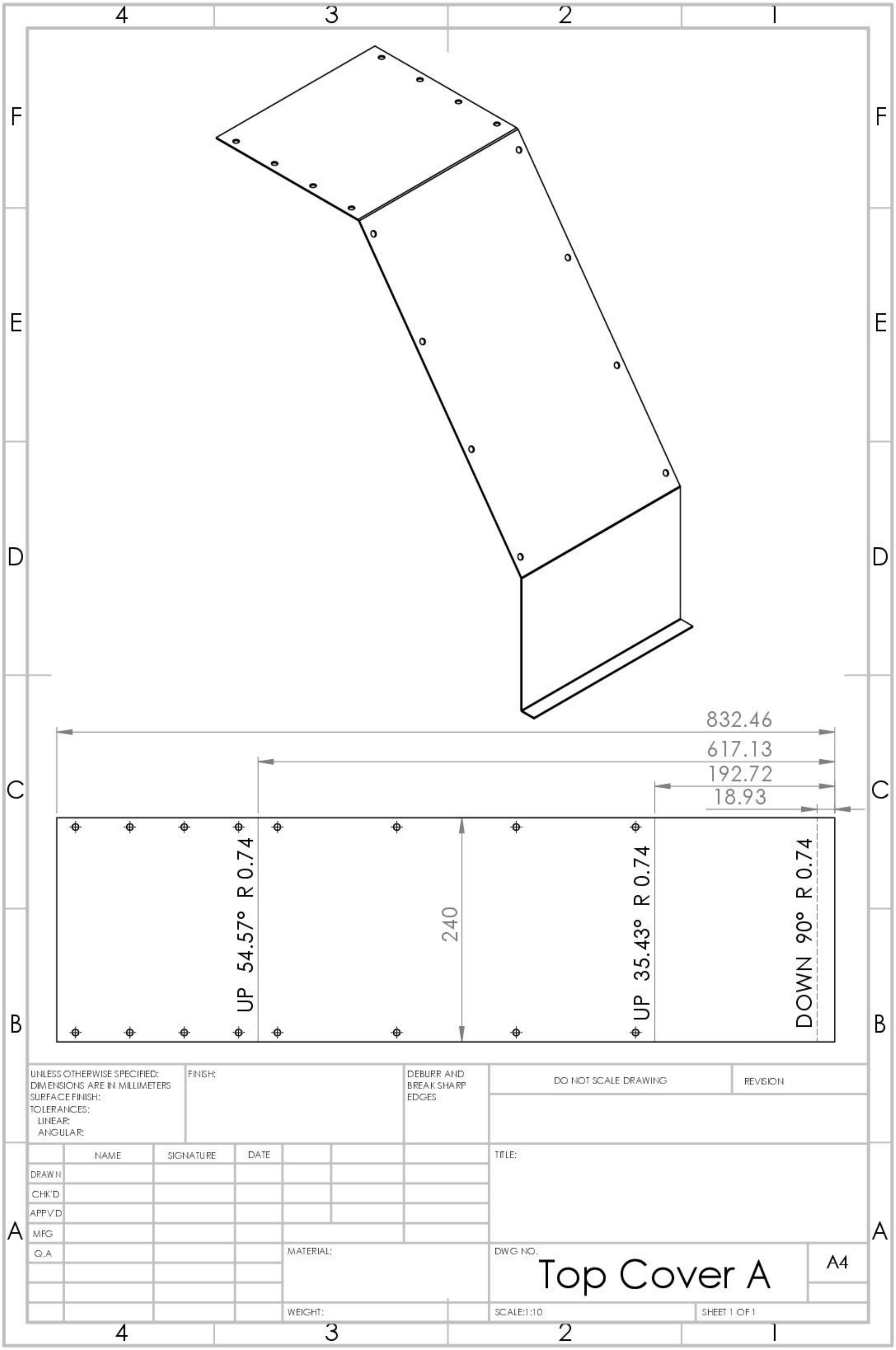
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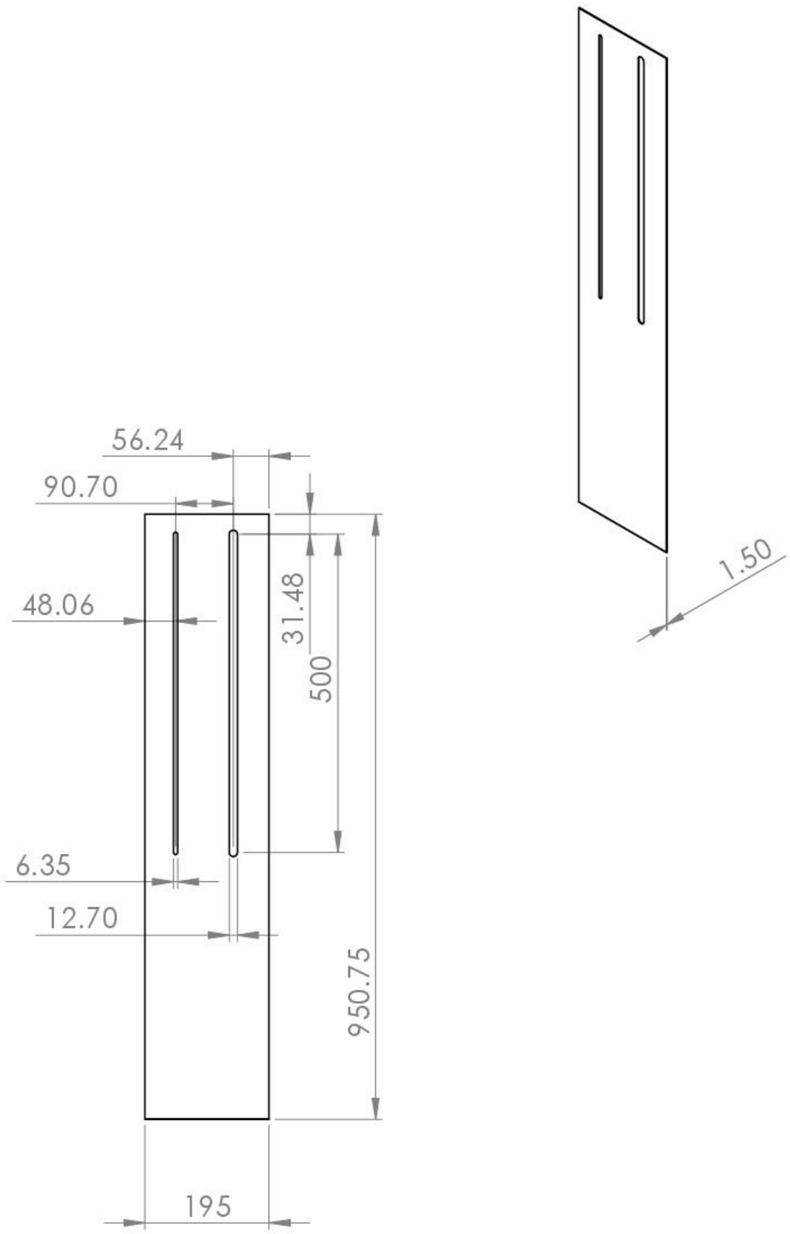

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Top Cover B

A4

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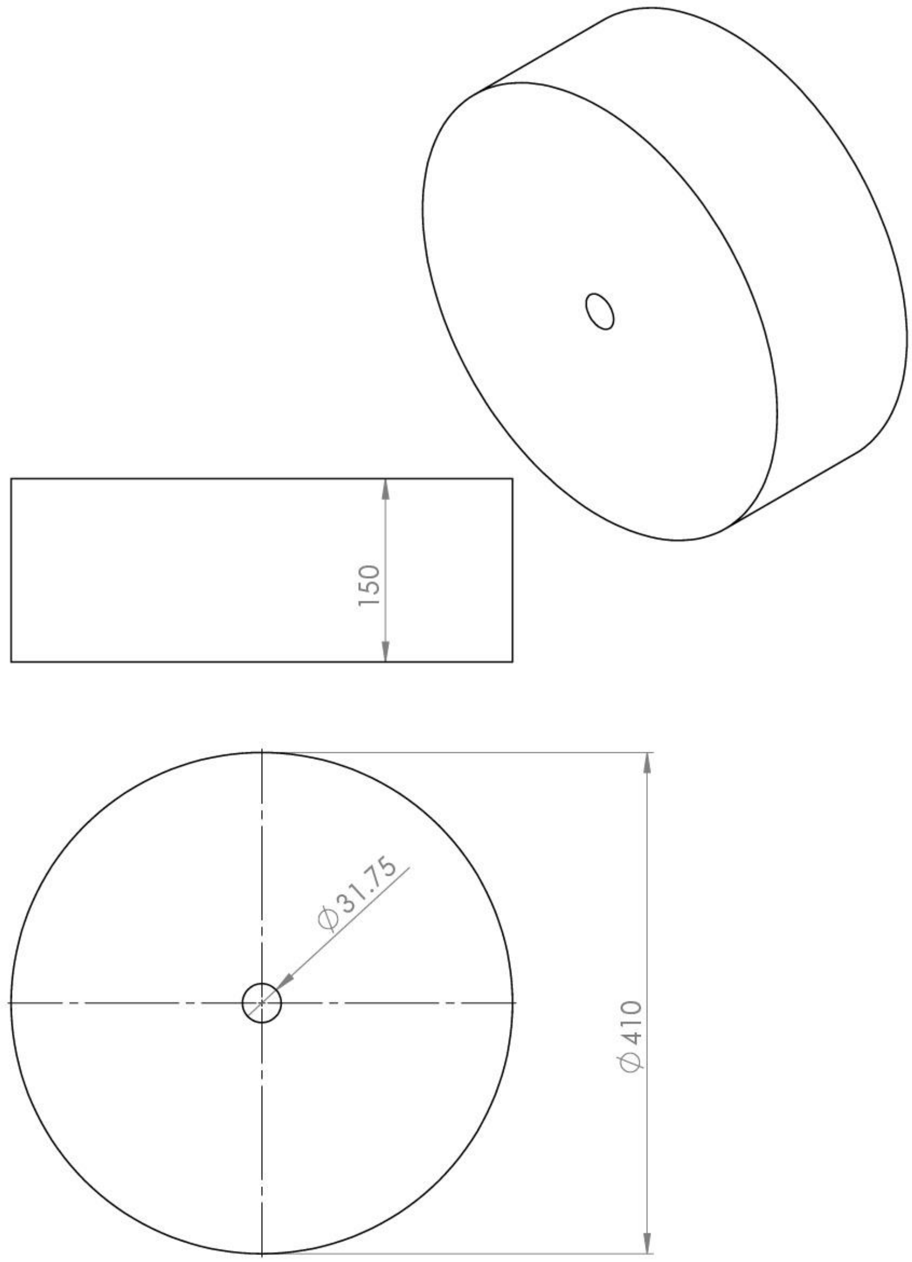
SHEET 1 OF 1



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DEBURR AND BREAK SHARP EDGES

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Top Drum

A4

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SHEET 1 OF 1