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# Thesis

**Submitted in partial fulfillment of the requirements for the Master's Degree**

# Reliability analysis of the pushing device of TSS company


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## *Dedication*

*This work is the result of months of hard work and was completed with the help and blessings of God.*

*I would like to dedicate this work to:*

*My whole world, my parents for their sacrifices, support, help, encouragement, constant prayers, deep trust, and endless love. Without them, I am nothing, and I wouldn't have reached this point.*

*My constant support and strength, my beloved siblings*

*All my family members and friends who always supported and encouraged me to keep going and give my best.*

## Abstract:

In this work, a reliability analysis of the pushing device, a crucial component in the production chain of the TSS unit at the El Hadjar complex was conducted. The analysis involves the failure and reliability assessment. While failure analysis identifies fault causes, reliability assessment estimates the chance of failure-free operation over time. A quantitative approach using Weibull's distribution along with a qualitative method through the Ishikawa diagram. The results showed that the locking finger of the pushing device has the highest failure rate due to multiple combined factors, which are summarized using the Ishikawa diagram within the analysis. Finally, the analysis presented in this thesis, might lead to reducing the failure rate and enhancing production efficiency in the production system.

## Résumé:

Dans ce travail, une analyse de la fiabilité du dispositif de poussée, un composant crucial dans la chaîne de production de l'unité TSS du complexe d'El Hadjar, a été réalisée. L'analyse comprend l'évaluation des pannes et de la fiabilité. Alors que l'analyse des pannes identifie les causes des défaillances, l'évaluation de la fiabilité estime la probabilité de fonctionnement sans panne dans le temps. Une approche quantitative utilisant la loi de Weibull a été combinée à une méthode qualitative via le diagramme d'Ishikawa. Les résultats ont montré que le doigt de verrouillage du dispositif de poussée présente le taux de défaillance le plus élevé en raison de plusieurs facteurs combinés, résumés à l'aide du diagramme d'Ishikawa dans l'analyse. Enfin, l'analyse présentée dans ce mémoire pourrait contribuer à réduire le taux de défaillance et à améliorer l'efficacité de la production dans le système de production.

## الملخص

في مجمع الحجار. TSS في هذا العمل، تم إجراء تحليل للموثوقية لجهاز الدفع، وهو مكون أساسي في سلسلة الإنتاج لوحدة يشمل التحليل تقييم الأعطال والموثوقية. بينما يحدد تحليل الأعطال أسباب الخلل، يقدّر تقييم الموثوقية احتمال التشغيل دون أعطال مع مرور الوقت. تم استخدام نهج كمي يعتمد على توزيع ويبل، بالإضافة إلى منهج نوعي باستخدام مخطط إيشيكاوا. أظهرت النتائج أن إصبع القفل في جهاز الدفع لديه أعلى معدل فشل، وذلك بسبب عدة عوامل مجتمعة تم تلخيصها باستخدام مخطط

إيشيكاوا ضمن التحليل. وأخيرًا، فإن التحليل المقدم في هذه الرسالة قد يسهم في تقليل معدل الفشل وتحسين كفاءة الإنتاج في نظام التصنيع.

# Nomenclature:

**SBS:** Bône iron and steel company (Société Bônoise de Sidérurgie).

**SNS:** The national steel company (Société Nationale de Sidérurgie).

**PMA:** Auxiliary Materials Preparation.

**ACO 1:** Slab steelmaking division.

**ACO 2:** Billet steelmaking division.

**LAC:** Hot rolling mill (Laminage à chaud).

**LAF:** Cold rolling mill (Laminage à froid).

**LER:** Wire rod and bar rolling mill division.

**ACE:** Electric steelmaking division.

**LAT:** Tube rolling mill (Laminoir à tube).

**PAT:** Finishing workshop (Parachèvement à tube).

**°C:** Degrees Celsius.

**NDT:** Non-Destructive Testing.

**Ø:** Diameter.

**WR:** Work Request.

**WO:** Work Order.

**MR:** Material Request.

**TZ:** Zone Technician.

**MTD:** The Maintenance Department.

**D:** Daily.

**W:** Weekly.

**B:** Bi-monthly.

**Q:** Quarterly.

**S:** Semi-annual.

**A:** Annual.

**M.O:** Maintenance Operations.

**IR:** Incident Report.

**PDR:** Spare Parts (Pièce De Rechange).

**FMECA:** Failure Modes, Effects, and Criticality Analysis.

**MTBF:** Mean Time Between Failures.

**TBF:** Time Between Failures.

**RAM:** Reliability, Availability, and Maintainability.

**RCA:** Root Cause Analysis.

**MTTF:** Mean Time to First Failure.

**MTTR:** Mean Time to Repair.

**MUT:** Mean Up Time.

**MDT:** Mean Down Time.

**F(t):** Cumulative distribution function.

**f(t):** Probability density function.

**λ(t):** Failure rate.

$\mathscr{F}(t)$**:** Empirical distribution function.

$R^2$**:** The coefficient of determination.

**η:** Scale parameter.

**R(t):** Reliability function.

**β:** Shape parameter.

**γ:** Location parameter.

**α:** Significance level.

**Dmax:** Test statistic.

**Dn, α:** Critical value.

**y:** The line equation.

**n:** Sample size.

**P:** Pressure.

**T:** Temperature.

**$P_0$:** Initial pressure.

**X:** Piston stroke.

**$V_0$:** Initial volume.

**S:** Cross-sectional area of the piston.

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# Introduction

# Introduction:

El Hadjar complex is a crucial player in Algeria's industrial sector. The national steel company (SNS), innovated on September 3, 1964, has been necessary in expanding Algeria's metallurgy sector and essence product metamorphosis. It now serves as a key supplier of raw steel to various national industries. Leveraging its strategic location near a port and rail links to the Ouenza mining area, the complex ensures efficient transport of iron ore and export of steel products. Having completed initial industry development phases, SNS is currently finalizing expansion plans to boost its annual steel production capacity to 400,000 tons.

Within this complex, the TSS unit (Tubular Seamless Section) is located in northeastern Algeria. It is the only manufacturer of seamless pipes in the Maghreb region, specializing in high-quality pipes for the oil and gas industry, with an annual production capacity of 90,000 tons. Established in 1976 to add value to domestically produced steel, the unit became part of ArcelorMittal’s pipe division in 2006, serving the mechanical, energy, and automotive sectors. Today, SIDER Tubular Product operates across four continents and in 11 countries through 21 operational sites.

Among the key equipment of the TSS unit is the pushing device, which plays a crucial role in ensuring the continuity and profitability of the production process. It is an essential machine used in the pipe rolling process, installed within a Pilger mill. Its primary function is to feed blanks into the rolling stand for further processing. The pushing device manages the various movements of the blank during its transformation into pipes and acts as a blank-handling system that enables seamless pipe rolling. The rolling is performed through the synchronized and simultaneous action of the pushing device and the rollers in the Pilger mill.

The main objective of this thesis is to analyze the failures of this specific machine (the pushing device). To achieve this goal, the thesis is structured into four chapters. The first one presents an overview of the TSS unit within the El Hadjar complex. The second chapter provides a detailed description of the pushing device and its main components. Chapter 3 covers general maintenance concepts and the specific maintenance practices implemented in the TSS unit. The last chapter focuses on analyzing the failures and reliability of the pushing device, aiming to identify the root causes of its frequent breakdowns and the resulting impact on production performance.

# Chapter I
# Presentation of the TSS Unit

## I.1 Introduction:

The SBS (Société Bônoise de Sidérurgie) was established in 1958 as part of the Constantine plan to build a blast furnace, which marked the beginning of the El Hadjar Steel Complex project.
Following independence, Algeria established the SNS (Société Nationale de Sidérurgie) in 1964 to complete the complex, which became operational in 1969 under President Houari Boumédiène. The sector was reformed in 1983, resulting in the establishment of SIDER, which was followed by the foundation of the SIDER Group in 1995 to transition to an economic business model. In 1999, a substantial restructuring resulted in the formation of Alfasid and 24 additional steel-making companies.
In 2001, a cooperation with LNM resulted in the development of Ispat Annaba and Ispat Tébessa, with LNM owning 70% and SIDER or Ferphos controlling 30%. These companies combined core steel production with iron mining operations.
Following various global mergers, the firm was renamed Mittal Steel Annaba in 2004 and ArcelorMittal Annaba in 2007. In 2013, a strategic agreement changed ownership to 51% SIDER and 49% ArcelorMittal, and the company was renamed ArcelorMittal Algérie. By 2016, ArcelorMittal had ceded all of its shares to Imetal, transforming the complex into a 100% Algerian public economic entity known as EPE SIDER El Hadjar [1].

## I.2 Production zones of the complex:

And are four zones as follows [2]:

1. Iron making zone :

    - Coking division;
    - Raw material preparation and sinter plants 1 and 2 (PMA);
    - Blast furnaces No. 1 and No. 2.

2. Flat products zone :

- Slab steelmaking division (ACO 1);
- Hot rolling mill division (LAC);
- Cold rolling mill division (LAF).

3. Long products zone :

- Billet steelmaking division (ACO 2);
- Wire rod and bar rolling mill division (LER).

4. Seamless pipe zone :

- Electric steelmaking division (ACE);
- Tube rolling mill division (LAT);
- Finishing division (heat treatment and threading) (PAT).

In addition, to meet its energy and fluid needs, the complex is equipped with:

- 63 thermal centers with a total capacity of 63,000 kW/h;
- 4 oxygen plants with a total capacity of 35,000 Nm³/.

## I.3 TSS presentation:

TSS is located within the industrial complex situated to the south of the city. Its mission was defined in two phases [2]:

• Phase One: The rolling mill is capable of producing 70,000 tons of finished pipes per year;

• Phase Two: Production is expected to reach 170,000 tons per year of finished casing and tubing.

The main reason for establishing a seamless pipe mill in Algeria was a major program for exploring and developing liquid and gaseous hydrocarbon fields [2]. The implementation of the corresponding wells requires tubular products which are [2]:

• Casing**:** used for well casing (structural support of well walls);

• Tubing: used as internal conduit in wells to lift liquid and gaseous hydrocarbons to the surface;

• Line Pipe**:** used for surface-level transportation between wells and collection centers.

## I.4 The TSS divisions:

Is divided into three divisions [2]:

1. ACE division: This division is designed to supply the seamless pipe plant with raw material (Ingots).

2. LAT division: This division includes:

   - A rolling workshop equipped with two Pilger mills: One 8" (3-C) and one 14" Pilger mill;
   - A finishing workshop for pipes;
   - An intermediate storage yard for pipes.

3. PAT division (Pipe Finishing Division): This division includes:

   - A product finishing workshop;
   - A coupling fabrication workshop;
   - A storage yard for pipes awaiting shipment.

## I.5 The TSS organizational chart:

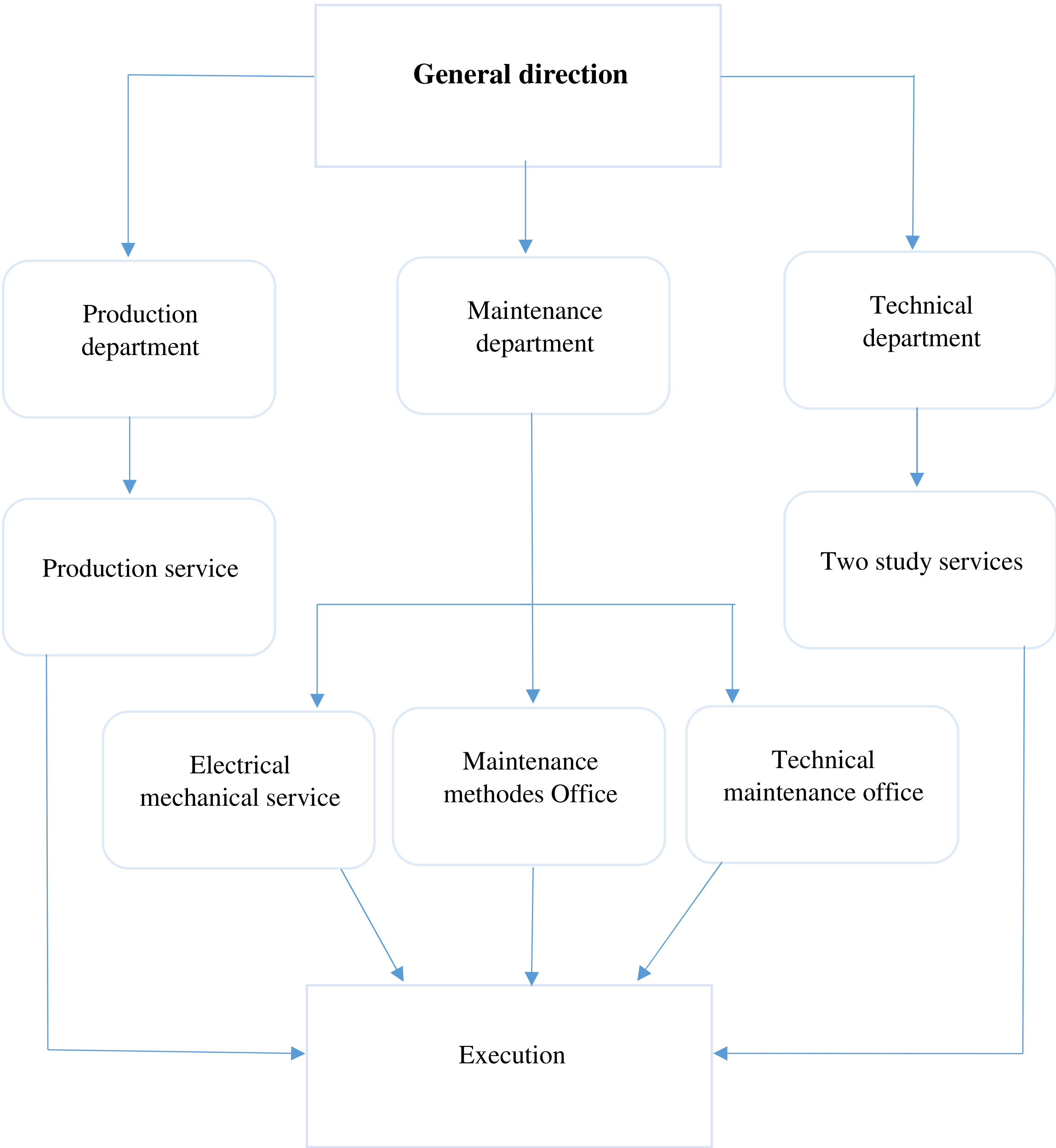


Figure I.1: TSS organizational chart.

## I.6 Tube manufacturing process:

The pipe manufacturing process involves two main workshops, which are as follows [3], [4]:

### I.6.1 Tube rolling mill (LAT):

- **Ingot Storage:**

Two types of ingots from the steel plant are stored in this yard:

- Round ingots with diameters of Ø190, Ø225, Ø270, Ø345;
- Dodecagonal ingots with diameters of Ø300, Ø350, Ø410, Ø500.

Figure I.2: Ingots storage.

- **Rotary hearth furnace:**

A rotary hearth furnace is employed to heat ingots or billets due to its temperature uniformity ($\Delta T \leq 30°C$) and production capacity (15 to 45 t/h).

Figure I.3: Rotary hearth furnace.

- **Piercing press:**

This equipment is used for piercing of ingots with a polygonal cross-section. To achieve this operation, a piercing mandrel is used, and it is driven by hydraulic cylinders powered by a hydropneumatic power unit.


Figure I.4: Piercing press zone.

- **Rotary table furnace:**

The rotary table furnace gently reheats products after they've been pierced, ensuring they're ready for the next stage of processing.

Figure I.5: Rotary table furnace.

- **Centering press:**

This equipment creates a pilot hole on the front face of round ingots, which facilitates their centering in the piercing oblique rolling mill, specifically on the head of the oblique rolling mill.

- **Oblique rolling mill:**

Transformation of round ingots or hollow blanks produced by the piercing press into pierced blanks. To achieve piercing, the products are driven onto a mandrel mounted on a fixed rod by moving and rotating them using two inclined rolls.

Figure I.6: Oblique rolling mill.

- **Pilger rolling mill:**

The TSS has two 8" mills and a 14" mill to produce rough pipes. Each Pilger mill consists of three main parts:

- The stand and feed mechanism;
- The carriage;
- The mandrel system.

Figure I.7: Pilger rolling mill.

- **The hot saw:**

A single, automatically operated saw is capable of making two or three cuts per roll of pipe. The front-end cut is performed visually, while the intermediate cut relies on a measuring rule, with a maximum pipe length of 15 meters. The end cut is executed using a mechanical stop. Accurate pipe positioning throughout the cutting process is ensured by a metal conveyor with adjustable speed.

Figure I.8: Hot saw.

- **Moving beam furnace:**

Pipes coming from the 14" Pilger and 8" Pilger mills need to be reheated.

Figure I.9: Moving beam furnace.

- **5-Stand sizing mill:**

Sizing and dimensional calibration by diameter reduction and cylindrical sizing of raw pipes produced by the 8" or 14" Pilger mills (After reheating in the furnace located before the sizing mill). Continuous processing through 5 alternating stands:

- 3 Stands with oval grooves (for reduction);
- 2 Stands with cylindrical grooves (for sizing).

Figure I.10: Stand sizing mill.

- **Finishing:**

  - **Pipe rotary straightener:**

The cold straightening process for pipes that come from the sizing mill involves using two sets of three rollers to drive the pipe (movement and rotation) and a central pressure roller.

Figure I.11: Tube rotary straightener.

- "**Bardons**" **sawing machine:**

The process of cutting pipes for mechanical testing involves cutting both the length and ends. Also, Beveling machine for the creation of bevels at the pipe ends.

Figure I.12: "Bardons" sawing machine.

- **Weighing and Measuring Installation:**

Equipped with a mechanical scale and a length measuring system using a pre-positioned mobile cursor before the pipe arrives.

**I.6.2 Finishing workshop (PAT):**

- **Quenching furnace:**

The quenching is carried out in water at temperature of approximately 900 degrees Celsius.


Figure I.13: Quenching furnace.

- **Tempering furnace:**

Internal stresses are relieved by tempering in ambient air at temperatures between 650 °C and 700 °C, in order to reduce brittleness and improvement of mechanical properties (elongation, impact toughness, etc.).

Figure I.14: Tempering furnace.

- **Non-destructive Testing (NDT):**

It has two types of inspections:

- Pipe inspection using the ultrasonic principle;
- Magnetic particle inspection, which is the visual inspection of magnetized pipes.

# Chapter II
# Pushing device description

## II.1 Introduction:

Rolling consists of elongating and thinning the blank on a cylindrical mandrel using two rotating rolls. It gives the metal bar a standardized profile and precise dimensions. The resulting product can be used as a finished item (such as rails, beams, pipes), or as a preform for forging or stamping [5].

## II.2 Description of the pushing device:

The pushing device serves to return the blank to its initial position after each rolling phase by means of horizontal translation, in order to allow a new rolling phase. It also performs a rotational movement of the blank (usually 90 degrees) between two rolling phases [4], and its main description is as follows [6]:

- A pneumatic unit of the air piston type;
- A reversible screw-nut system providing a quarter-turn rotation;
- A water brake used to stop the blank in the forward position.

### II.2.1 The necessary organs for translational movements (air piston):

Translation is ensured by:

- A chamber supplied with primary air, the base of which is adjusted by a screw-nut system. Its air supply is provided by a central needle with radial ports [6].

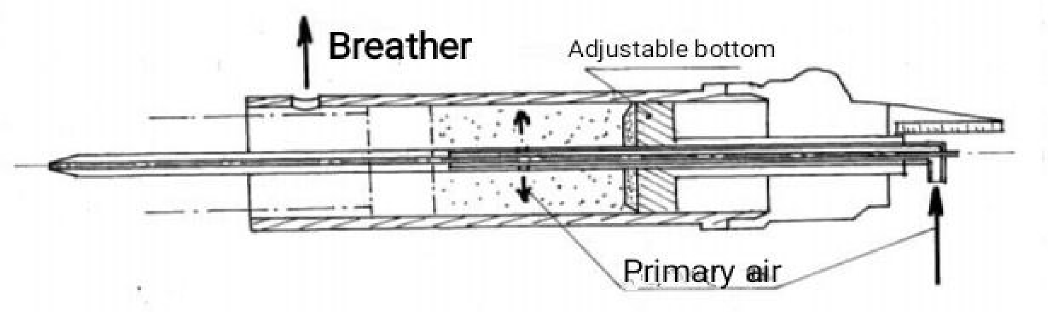


Figure II.1: Air piston [6].

- A piston moving within the chamber is connected to [6]:

  - A helical guide rod;
  - A mandrel holder tip;
  - The male part of the water brake.

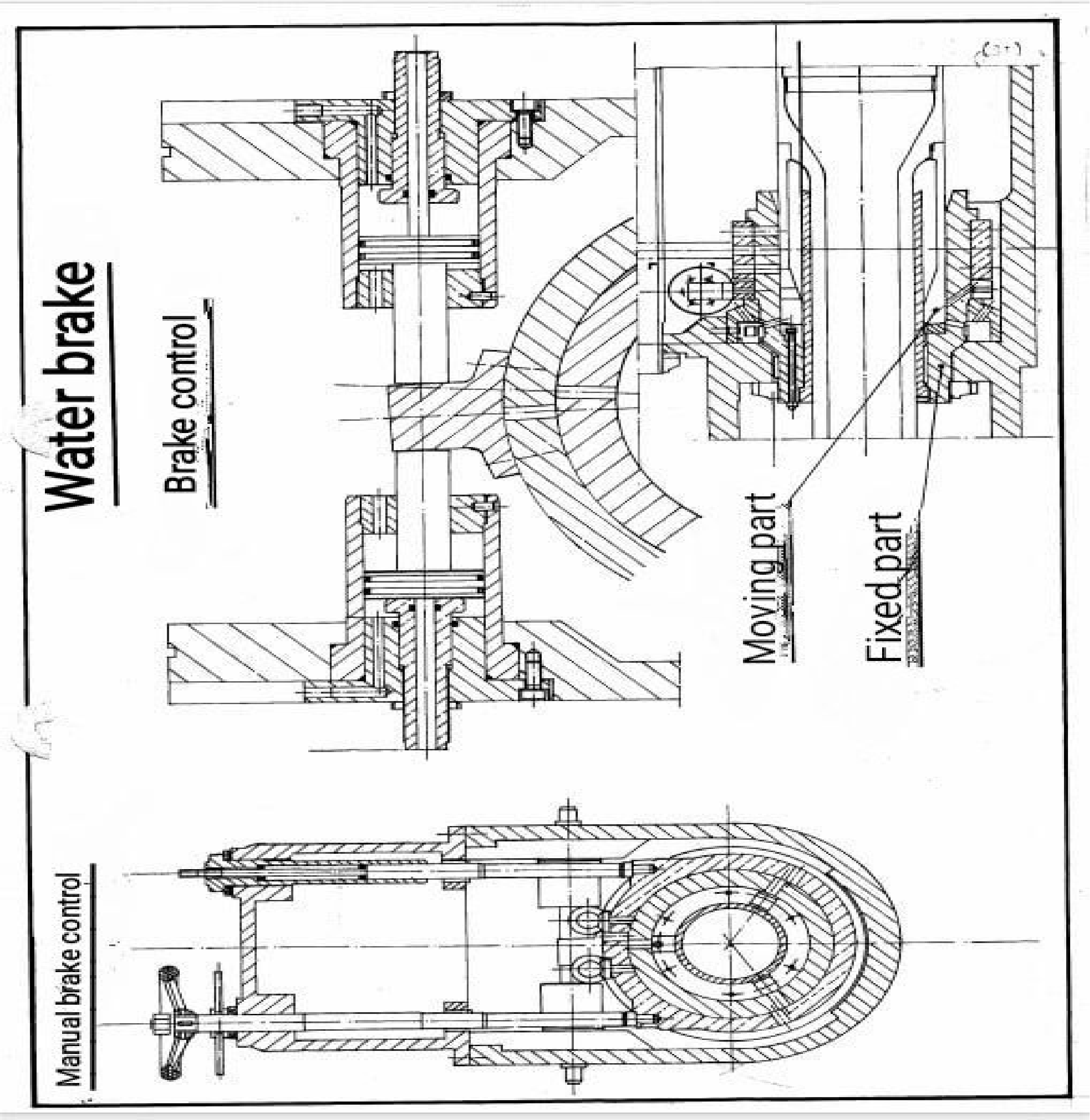


Figure II.2: Water brake [6].

| Pilgrim | Maximum chamber length | Ø of the piston |
|---|---|---|
| 14" | 1310 mm | 590 mm |
| 8" | 910 mm | 480 mm |

Table II.1: Maximum lengths of chambers and diameter of the pushing device [6].

The volume of the compression chamber between the piston and the device's base is adjustable to attain a compression ratio appropriate for each gauge, thereby accommodating the stroke and rotating speed of the rollers [6].

### II.2.2 Required components for rotation:

- A nut mounted on the helical shaft;
- A set of gears allowing coupling between the nut and the freewheel;
- The freewheel cage is coupled to a hydraulic motor, which allows correction in either direction relative to the correction angle [6].

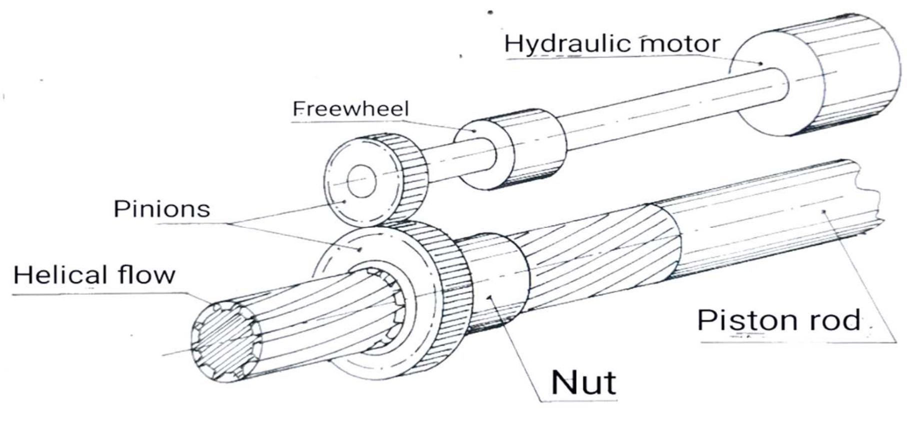


Figure II.3: Required components for rotation [6].

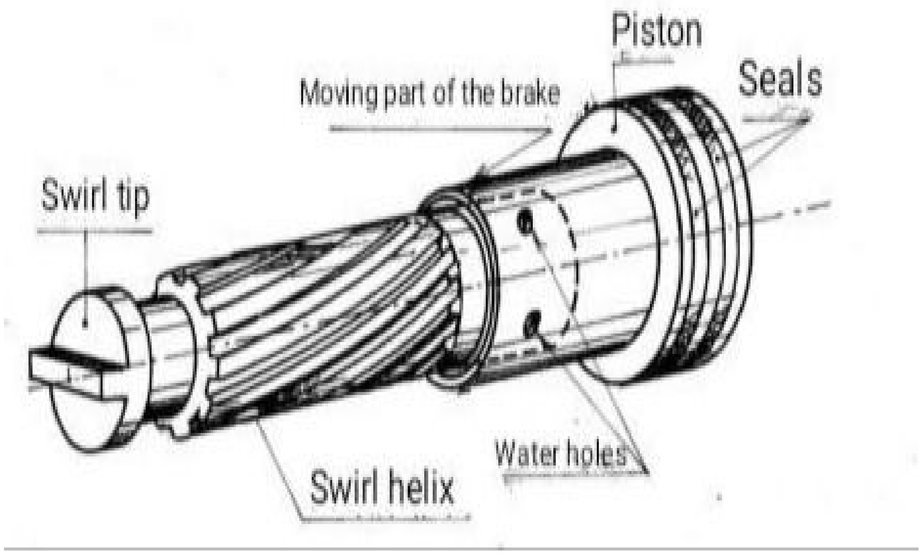


Figure II.4: Piston-swirl assembly [6].

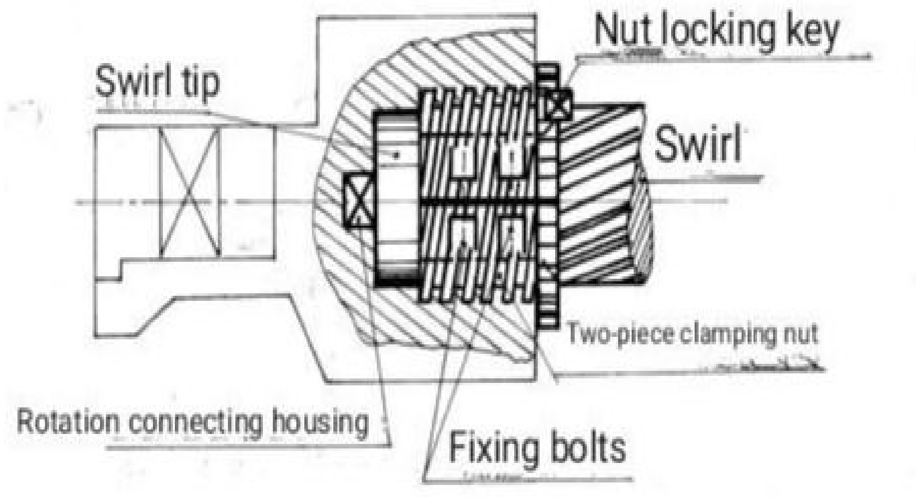


Figure II.5: Mandrel holder fixed to the swirl tip with a two-piece clamping nut [6].

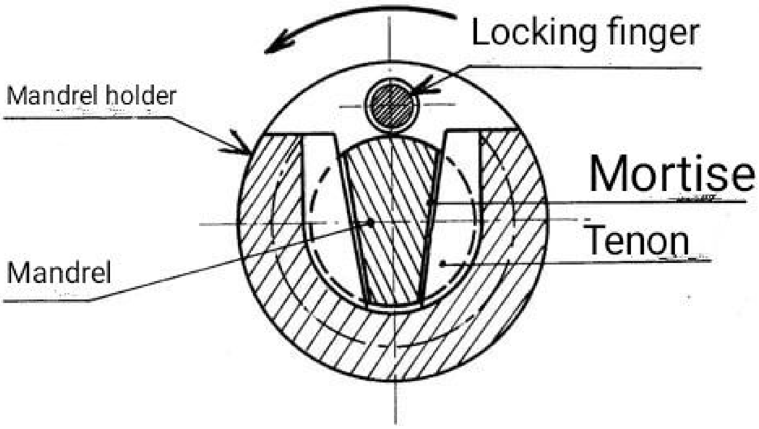


Figure II.6: A pneumatically controlled locking finger allows the mandrel to be held in place during its rotation [6].

## II.3 Operation of the pushing device:

- **Pointing phase:**

The carriage moves the pushing device forward toward the rolls, with the piston in the forward position under the effect of primary air pressure (1 bar). When the blank comes into contact with the rolls, they impart a translational (back-and-forth) motion to the blank until the maximum rejection stroke is reached. During this phase, the blank 's rotation is too slow due to insufficient stroke. Consequently, it must be given a rotational movement via a hydraulic motor. The pointing phase is therefore a transitional phase characterized by the search for synchronism alignment between the rolls' rotational speed and the pushing device’s back-and-forth movement [6].

- **Rolling:**

When synchronization is accomplished, the carriage causes the gadget to move ahead continuously. A section of the blank, based on the feed rate, is gripped by the rolls, elongated by the attack rollers, and smoothed by the finishing rollers, while the rolls push the entire blank – piston assembly backward. The piston compresses the air in the chamber. The energy thus accumulated will be released when the rolls let go of the material in the false groove. The blank – piston assembly is then returned to the rolls while executing a quarter-turn rotation (90°). This forward movement is slowed by a brake positioned at the front. Hydraulic (Water Brake) is adjusted in such a way that the speed of the entire assembly is zero at the exact moment the blank is compressed by the rolls. This cycle repeats until the end of the rolling process [6].

- **Mandrel removal (demandreling):**

The mandrel removal operation is carried out by the pushing device. The piston is brought back to the fully forward position to come into contact with the end of the water brake [6].

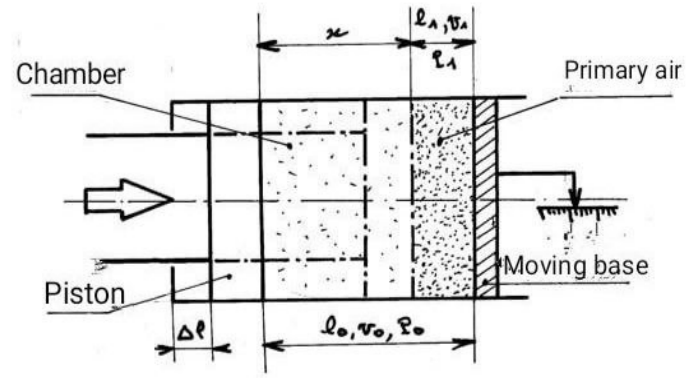


Figure II.7: Working principle of an air piston [6].

The compression of air in the chamber due to the recoil of the piston is an adiabatic transformation. That means without heat exchange with the exterior [6].

### II.3.1 Water brake:

It serves to absorb the kinetic energy of the moving masses. Synchronization between the rotational speed of the cylinders and the return speed of the blank requires the blank to have zero speed when the cylinders come into contact with it. The deceleration and stop of the blank are achieved by the water brake, whose profile is schematically illustrated below [6].

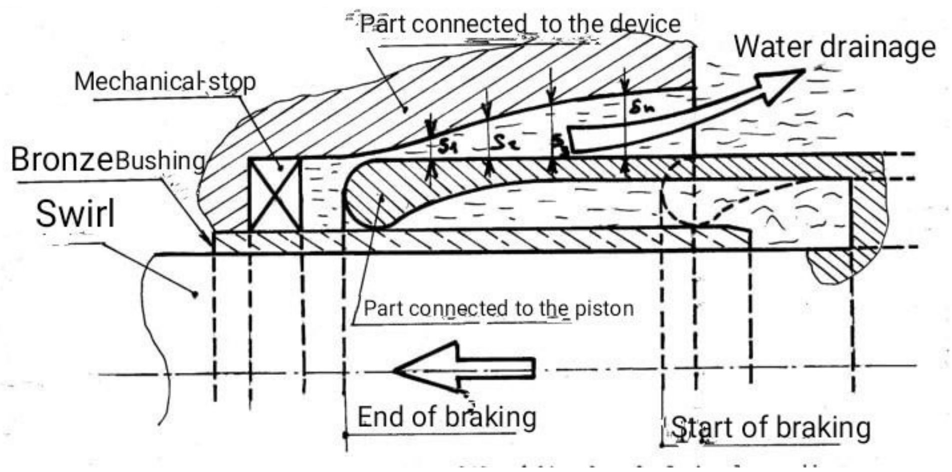


Figure II.8: Brake profile [6].

As the moving part enters the brake, the water evacuation sections (S1, S2, S3, etc.) decrease, which increases the resistance to penetration. This resistance must correspond to the inertia of the moving masses and the return speed. The masses and speeds vary depending on the pipe format. Consequently, the variation in forward resistance is achieved through adjustable throttling orifices [6].

| **Pilgrim** | **Propeller Pitch** |
|---|---|
| **14** | **3600 mm** |
| **8** | **2700 mm** |

Table II.2: helix pitches [6].

The natural rotation angle is directly proportional to the piston's stroke. During rolling, the cylinders reject the blank toward the same pushing side while remaining immobilized in rotation. It is then the nut that turns with a degree of rotation proportional to the rejection stroke. When the cylinders release the material, the air release sends the whole set back by the cylinders at the same rotation angle. For this, the nut must be locked. The rotation always takes place in the same direction, a freewheel-type device allows this to happen [6].

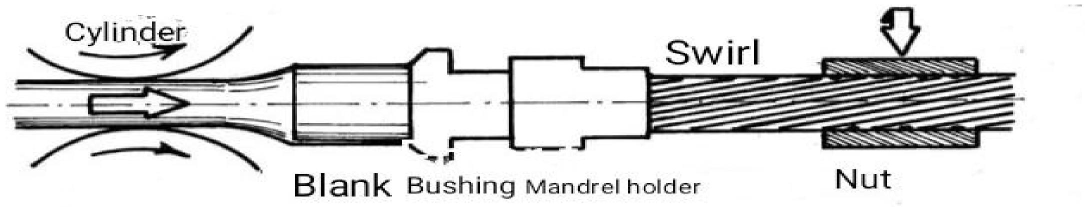


Figure II.9: Swaging process diagram [6].

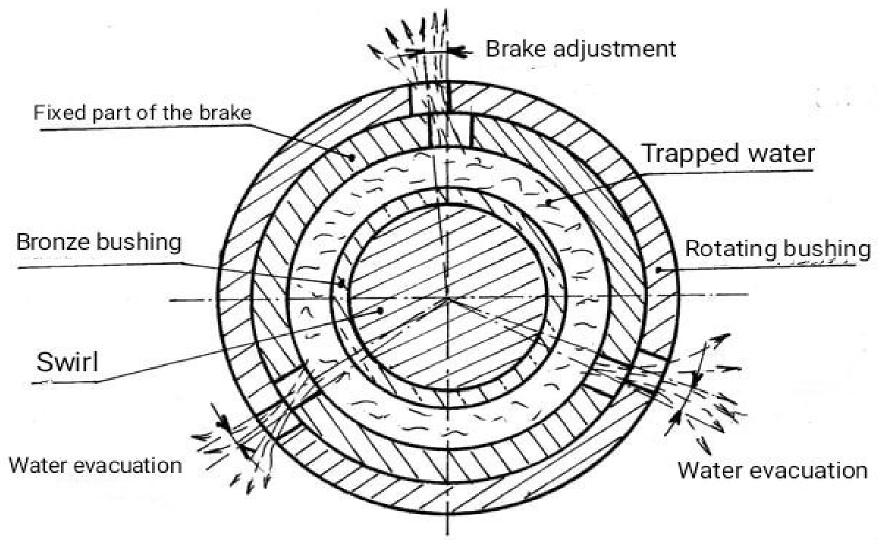


Figure II.10: Swirl brake system diagram [6].

### II.3.2 Drall rotation:

During the return of the mandrel-piston assembly by air release, a reversible screw-nut system, in which the nut is held stationary in rotation, transmits the helical forward motion [6].

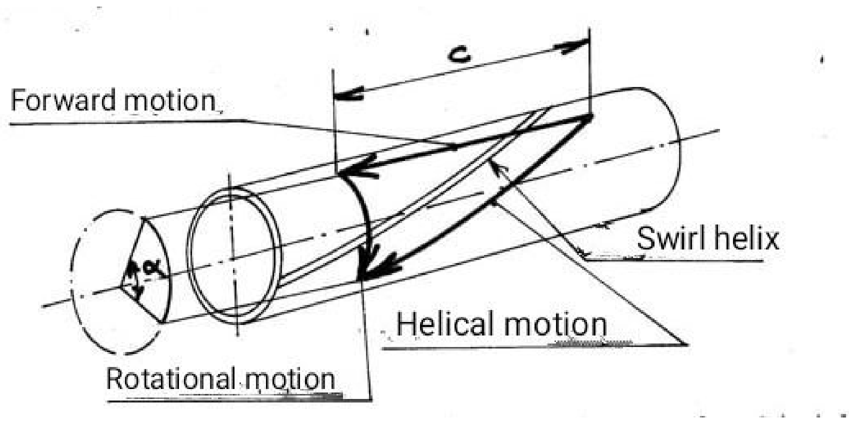


Figure II.11: Swirl helix motion diagram [6].

The rotation angle of the mandrel depends on the rejection stroke and the pitch of the helical screw (drall), α natural rotation = (360 × stroke) / pitch [6].

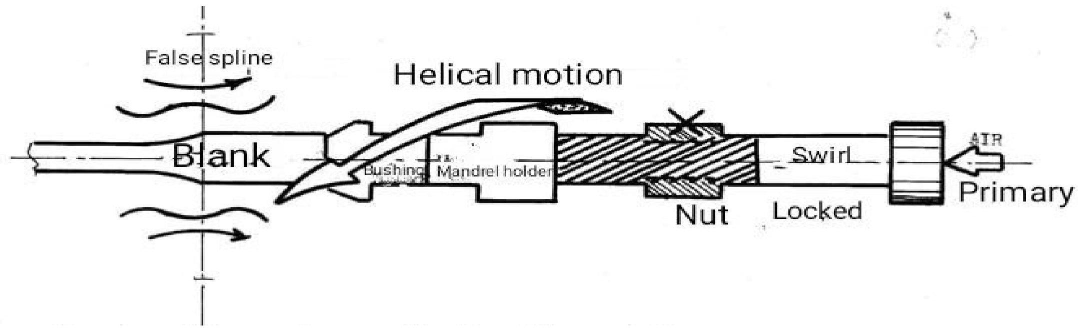


Figure II.12: Rotary swaging process for helical spline formation [6].

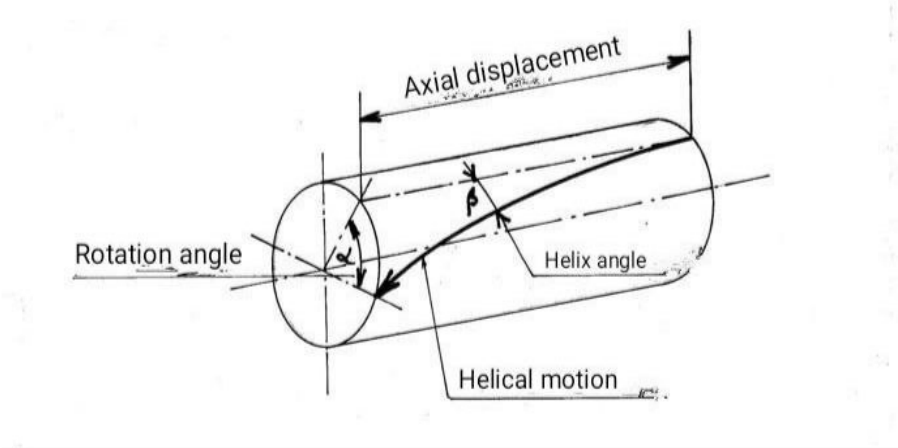


Figure II.13: Helical motion of the blank during swaging operation [6].

### II.3.3 Rolling cycle diagram:

Schematic representation of the rollers and the piston during the operation of the pushing device.

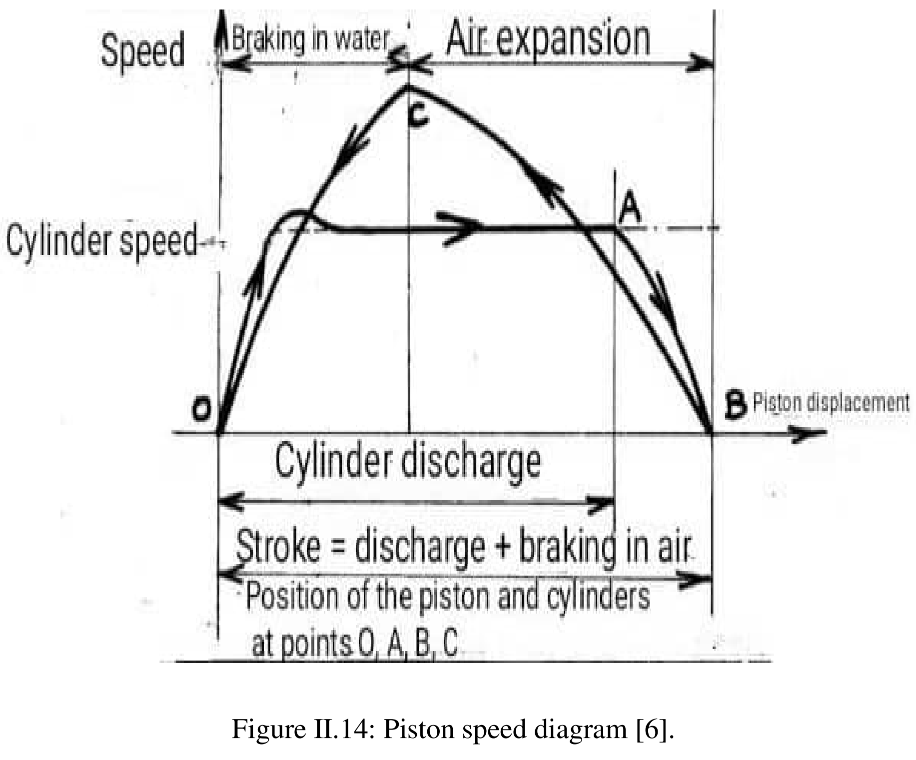


Figure II.14: Piston speed diagram [6].

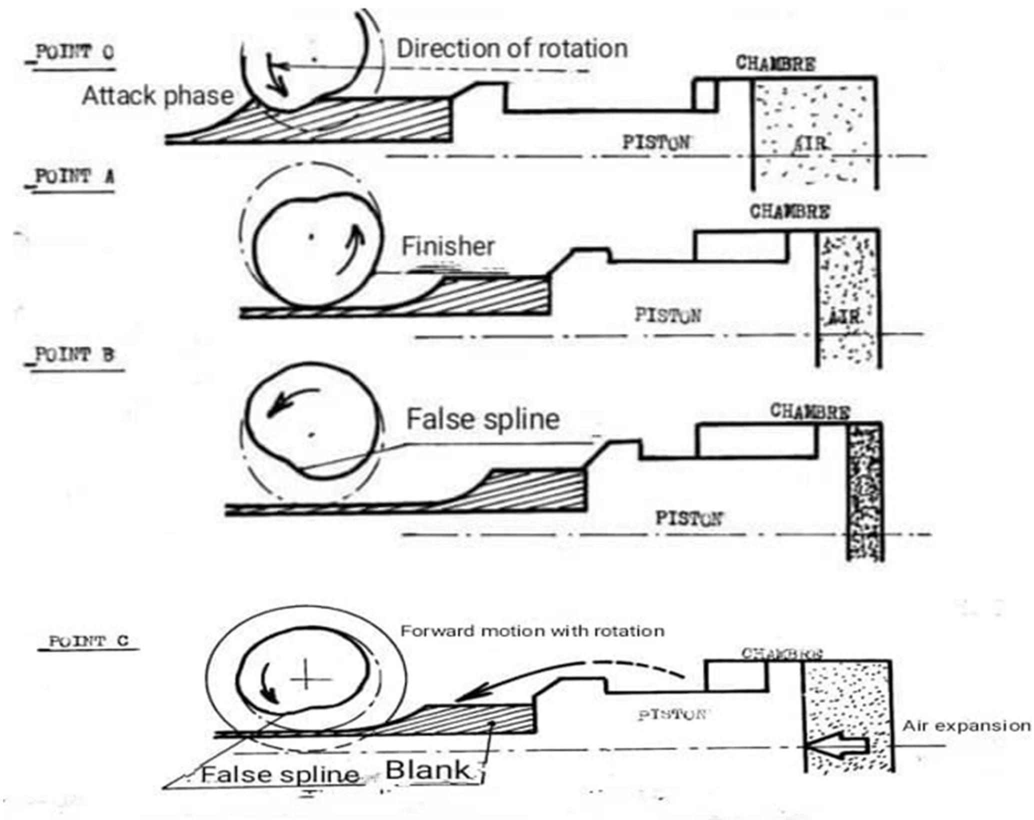


Figure II.15: Rolling cycle diagram [6].

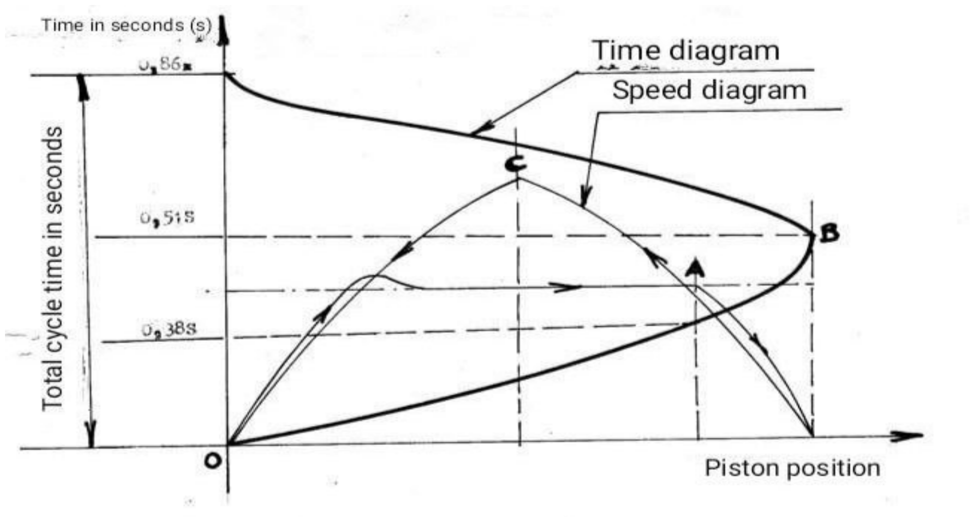


Figure II.16: Time and speed diagram for piston motion [6].

# II.4 The carriage:

## II.4.1 Description:

It receives the pushing device and ensures forward movement during rolling and backward movement for mandrel removal. The kinematic chain includes [6]:

- A direct current electric motor;
- A reducer;
- A floating shaft;
- A screw to transmit forward and backward motion to the carriage;
- A nut.

➢ **Characteristics of the kinematic chain:**

| **Cages** | **Power (kW)** | **Speed (rpm)** | **Stroke (mm)** | **Max. Thrust (T)** | **Forward Speed (m/s)** | **Return Speed (m/s)** | **Thrust Speed (m/s)** |
|---|---|---|---|---|---|---|---|
| 14" | 302 | 500-1000 | 6400 | 140 | 0.008 - 0.08 | 0.6 | 0.1 |
| 8" | 220 | 500-1000 | 5140 | 90 | 0.008 - 0.08 | 0.6 | 0.1 |

Table II.3: Characteristics for the kinematic chain [6].

➢ **A height adjustment device:**

It allows the machine to be aligned with the rolling axis. It includes: A pneumatic motor driving a screw with a right-hand thread and another with a left-hand thread. This allows two corners to be moved apart or brought closer together [6].

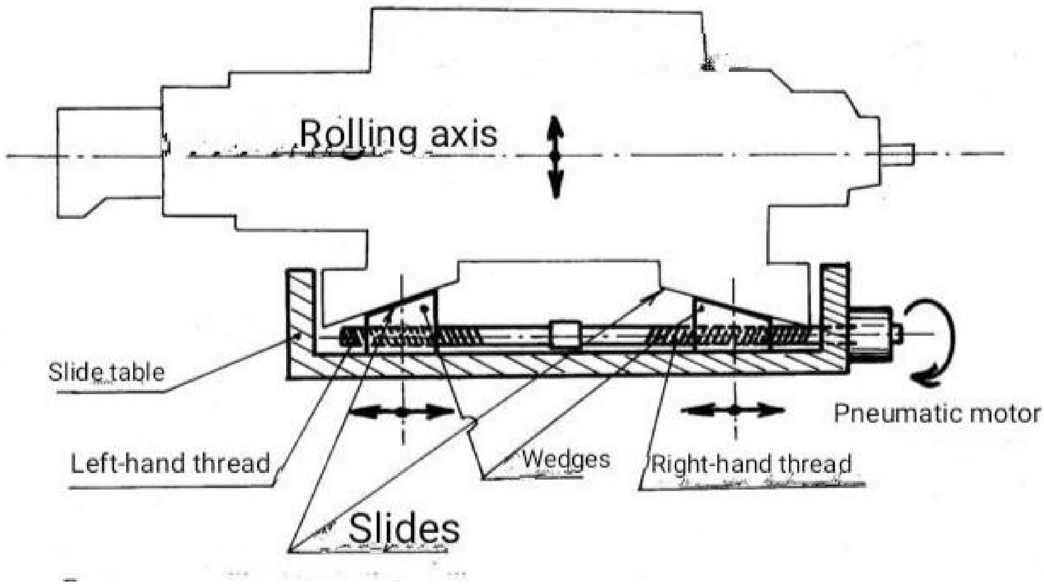


Figure II.17: The pushing device [6].

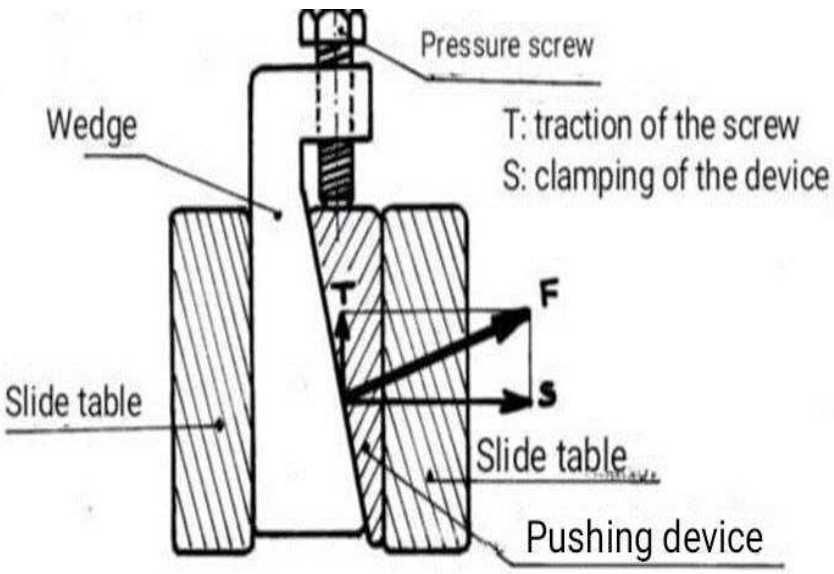


Figure II.18: A manual locking system for the device [6].

### II.4.2 Unmandreling efforts:

The unmandreling operation is carried out by the electric motor, which moves the carriage backward through its kinematic chain. The unmandreling effort is caused by the clamping of the pipe into the mandrel (due to cooling and friction between the pipe and the mandrel). These efforts depend on the temperature at the end of the rolling and the mandrel's graphitization [6].

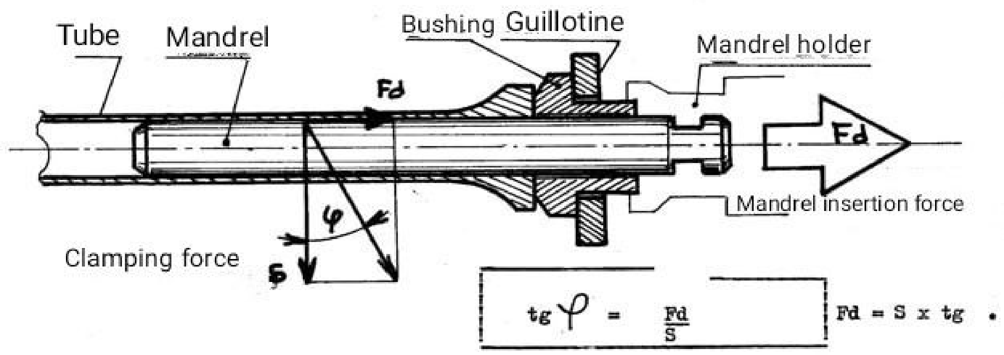


Figure II.19: Breakdown of mandrel insertion force [6].

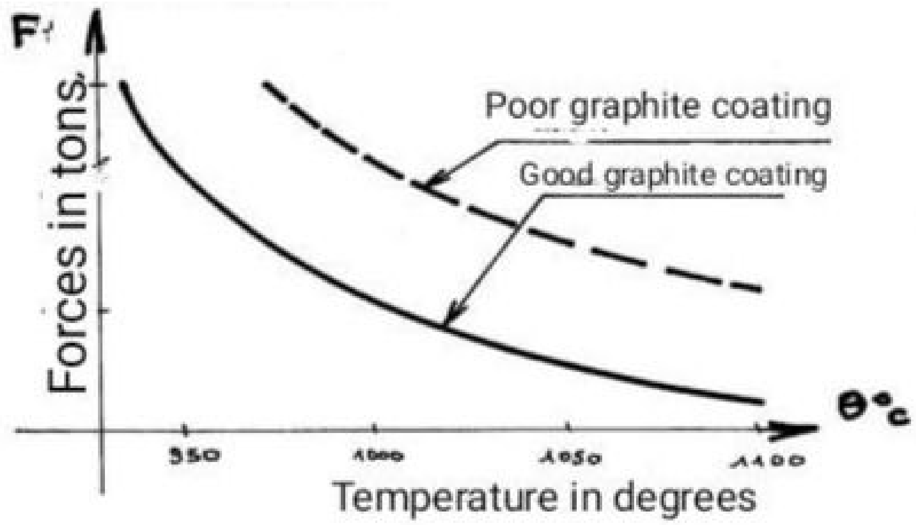


Figure II.20: Relationship between forces and pipe [6].

## II.5 Positioning of the pushing device within the production chain:

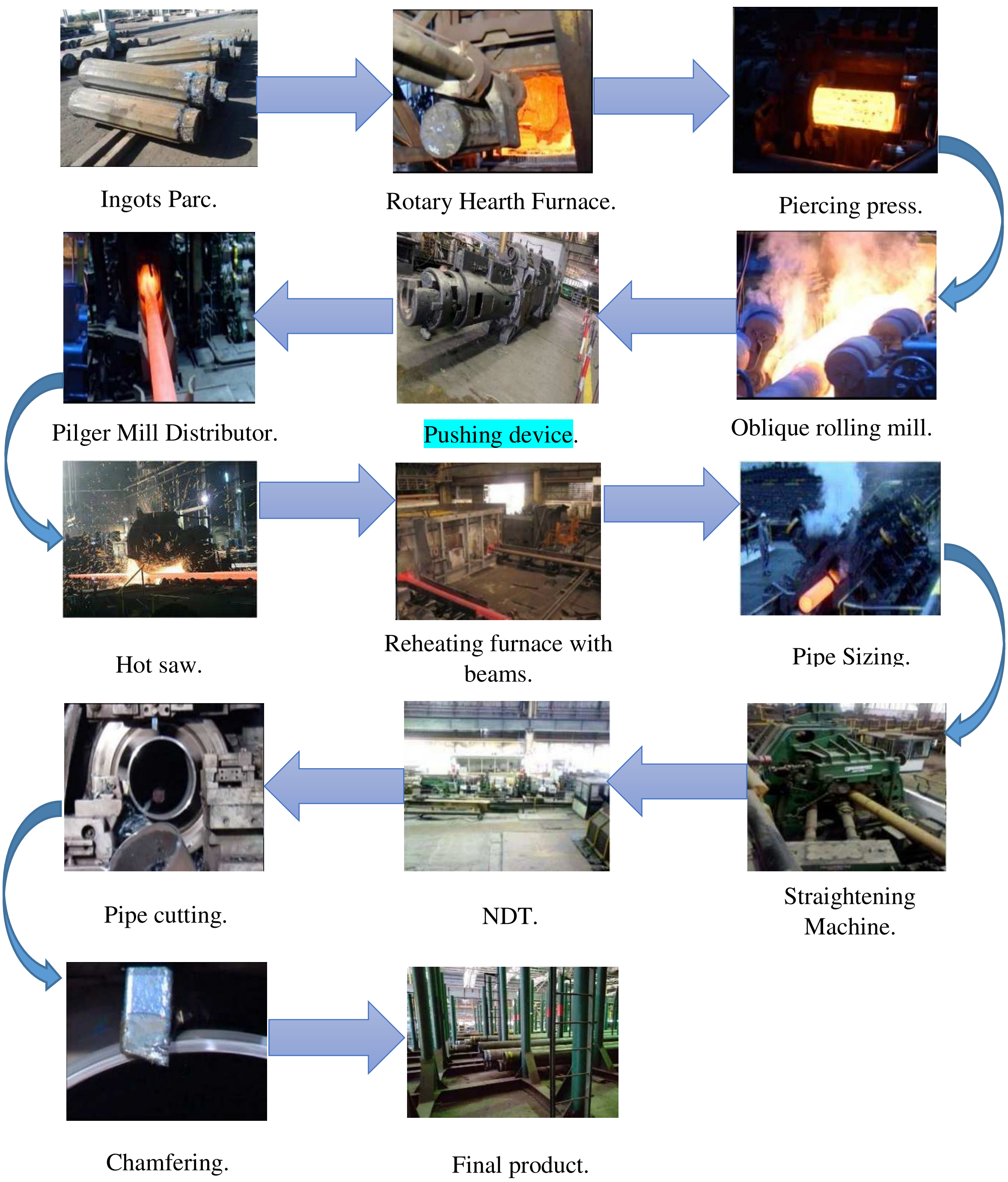


Figure II.21: The production chain.

# Chapter III
# Maintenance performed at the TSS

## III.1 Introduction:

In today's world, rotating machinery can be found in many industrial uses. The role of these machines is so significant that any flaw could result in production losses, equipment damage, or even compromise the safety. For these reasons, industrial maintenance has become a key issue for the durability of machines and mechanical installations, which in turn is essential for increasing the productivity of production units [7].

## III.2 History:

In the 12th century, the French language used the term 'maintenance', which was derived from the Latin words 'manus' (hand) and 'tenere' (to hold). Wace, the etymologist, discovered that the term main-teneor (meaning 'the one who supports'), was used in 1169 as an outdated term for maintainer (maintainer). Over the past twenty years, we've seen that the maintenance department has evolved from previous structures, including traditional maintenance services. These maintenance services have been present in industry since the beginning of the industrial era, where they were initially a sub-function of production. Often marginalized within companies, they were based on specific trades: Mechanical repair technicians, electrical repair technicians, lubricators, and adjusters all working separately and often in conflict with the "producers/destroyers" of machines ("you break it, I fix it"). Maintenance was mainly focused on troubleshooting and repairing after failures, with the primary concern being restarting quickly. Only a minimal amount of preventative measures were implemented, including lubrication and periodic monitoring rounds [8].

## III.3 Definition:

A maintenance operation can be defined as a series of organized actions carried out on a system, with a dual objective [9]:

- First objective: To restore an asset that is malfunctioning and return it to working condition, enabling it to produce again;

- Second objective: To maintain that asset through a series of preventive and planned actions, keeping it in perfect working condition, and therefore, capable of producing.

In general, the maintenance department must keep the production equipment in operational conditions to ensure efficient and maximum production [9].

## III.4 Preventive operations:

Preventive measures can be classified into three basic groups [9]:

- Inspection visit: Inspection visit is a preventative maintenance service, conducted to monitor operation. It can include an in-depth examination of all or part of the system that is being monitored;
- Control: The objective of this operation is to check whether certain conditions are met, or if certain data is already present. It relies on established validation resources;
- Inspection: This is the act of looking closely and in detail to keep watch. It is also able to observe how a discovered fault develops over time without interference during a scanning inspection.

These three checks (visit, control and inspection) are scheduled within the scope of preventive maintenance. Once the defects identified and recorded are the result of the evolution of the defects observed, these may then be the cause of corrective maintenance operations.

## III.5 Objectives of maintenance:

The aims of maintenance are divided into two main classes [5]:

### III.5.1 Cost-related objectives:

- Reduce the cost of maintenance;
- Budget, according to maintenance costs;

- Adjust maintenance spending to more closely match the servicing requirements of the assets, based on their age and usage level;
- Allow the maintenance manager to cover a certain amount of unexpected expenses.

### III.5.2 Operational objectives:

- Maintain the asset in a state of good repair:
    1. In an acceptable state ;
    2. Under optimal conditions.
- Guarantee a high level of availability with a reasonable price;
- Eliminate breakdowns at all times and minimum cost;
- Extend the life of the asset;
- Replace the asset for a set period of time;
- Get top-quality performance from the asset;
- Operating in a safe and effective manner asset;
- Get the most bang for your buck;
- Preserve, an acceptable condition of the asset;
- Make certain that the asset is kept in an immaculate state of cleanliness.

## III.6 Maintenance types:

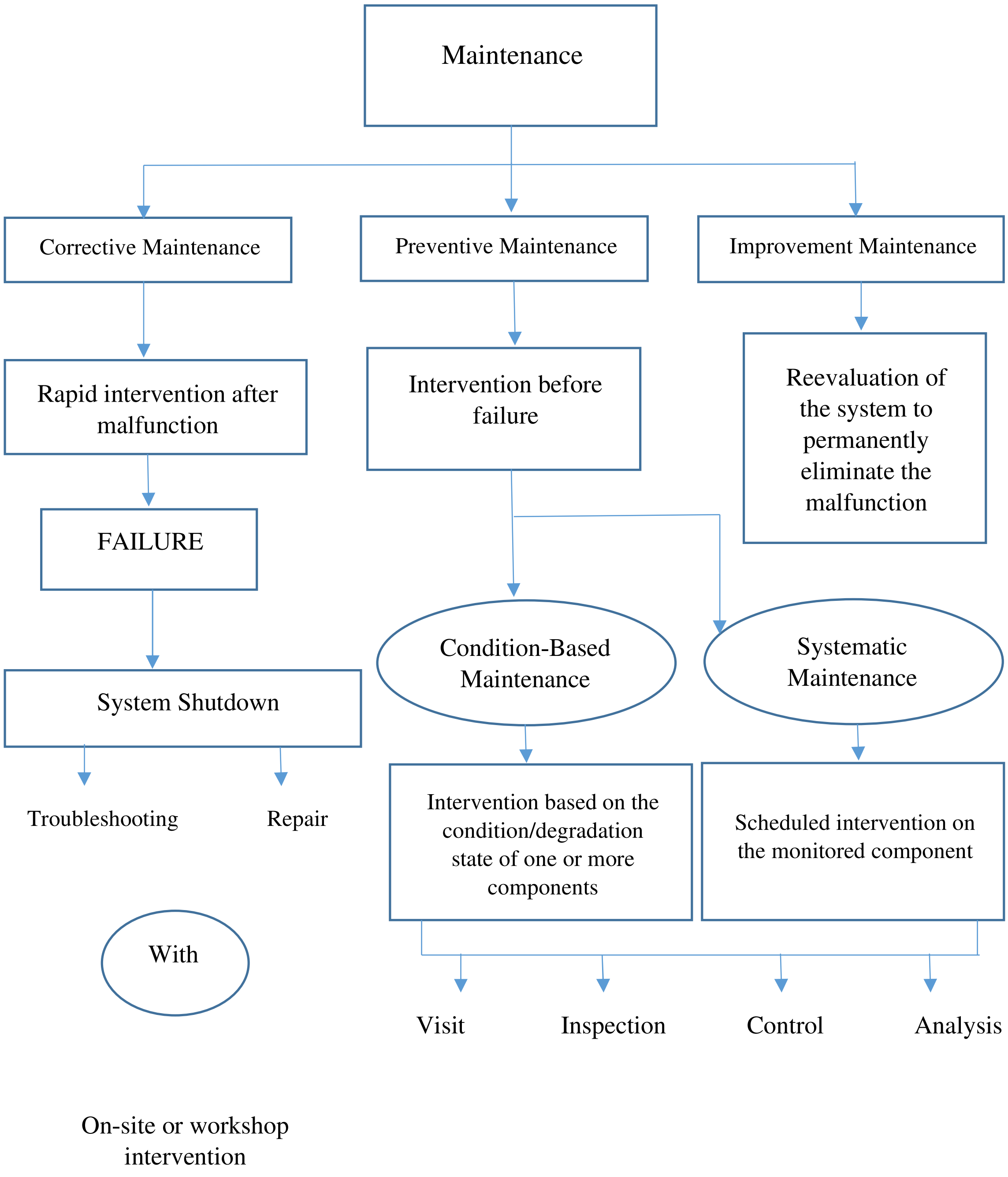


Figure III.1: Maintenance types [9].

## III.7 Definition of maintenance costs (NF X60-020):

Maintenance costs involve all expenses that are directly connected to maintenance activities. They can be classified:

- By nature, labor, tools, consumables, subcontracting, etc;
- Destination-related tasks include preparing, technical documentation, interventions, storage, and training;
- Intervention types include preventive, corrective, overhaul, or new works.

Maintenance costs may be classified as operating expenses or capital investments, and may also include financial charges like inventory ownership or storage.

Downtime costs cause unavailability costs which include production losses, variable costs that are not recoverable, fixed overhead costs, quality-related losses (scrap, rework), extra labor, emergency replacements, lost revenue, penalties, and reputational damages.

Failure costs are the sum of corrective maintenance costs and the downtime costs caused by equipment failure [9].

## III.8 Role of the maintenance department within a company:

A company's purpose is twofold [9]:

1. From an economic perspective:

Investing capital, whether public or private, is done with the goal of maximizing profit through the production of goods or the delivery of services.

2. From a social perspective:

It contributes to the broader social good by promoting access for wider segments of society to greater safety, well-being, and both individual and collective fulfillment.

## III.9 The maintenance document flow diagram:

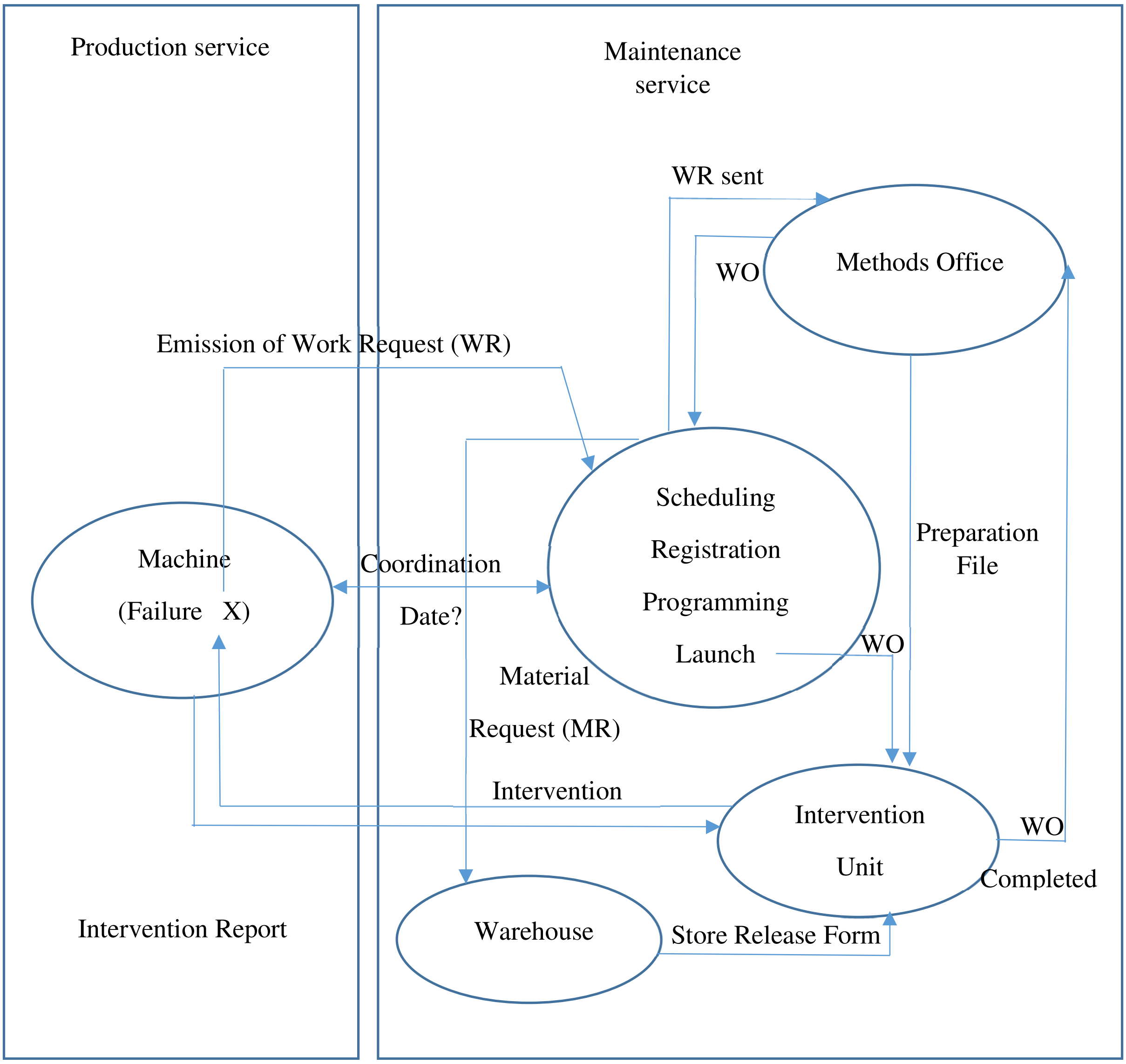


Figure III.2: Flow diagram [8].

## III.10 The maintenance procedure within TSS:

### III.10.1 Preventive maintenance:

Maintenance performed based on predetermined criteria to decrease the likelihood of equipment failure or deterioration of service [10].

- **Conditional maintenance:**

These are maintenance tasks whose necessity becomes apparent during visits, inspections, and checks. The zone technician (TZ) and their team leader create a plan for scheduling inspections and tasks from predictive maintenance calendars. Following an inspection, the TZ, depending on the situation, issues a work order (BT) for urgent cases, which is either forwarded to the Intervention Team or handed over to the methods department to be included in the scheduled maintenance plans. The maintenance department (MTD) receives a visit report and work orders for follow-up. TSS is working on developing conditional or predictive preventive maintenance by using new measurement and monitoring tools for key indicators, such as pressure, temperature, current, and so on, and the execution team will carry out these measurements in a systematic way. MTD will analyze the trends from these measurements, and in collaboration with the technical department, they will define the frequency and scheduling of future maintenance activities [10].

- **Systematic maintenance:**

Maintenance standards are followed by a calendar that outlines the total number of work weeks throughout the year and the various installations that must be maintained. Based on this calendar, a schedule of systematically planned tasks with varying frequencies (D = Daily; W = Weekly; B = Bi-monthly; Q = Quarterly; S = Semi-annual; A = Annual) is prepared by the zone technician (TZ), along with the corresponding work orders (BT). Each of these documents is produced in duplicate, with one copy being used for execution and another being kept by the TZ. A specific number of hours are set aside in the calendar time during the development of the production business plan to perform this type of maintenance. After the technical department finishes the maintenance tasks and closes the schedules, they send the completed planning documents and work orders to the methods department for monitoring and analysis. The maintenance department (MTD) receives a weekly report from the TZ that lists downtimes and corrective actions taken [10].

### III.10.2 Corrective maintenance:

Corrective maintenance includes any actions taken after an asset has failed or its function has deteriorated, intended to enable it to perform its required function temporarily. It has the potential to be either palliative or curative [10]:

- **Palliative corrective maintenance:**

This involves corrective maintenance actions that aim to temporarily enable an asset to perform all or part of a required function.

- **Curative corrective maintenance:**

Activities of corrective maintenance are designed to restore an asset to its intended condition or enable it to perform a required function. The aim of these actions, like repairs, modifications, or enhancements, is to have a lasting impact.

### III.10.3 Annual shutdown:

And it is represented in the following steps [10]:

- **Review previous shutdown:**

Study last year’s problems and learning to better plan.

- **Work list:**

Task as a function of machine criticality, previous incidents and future production necessity. Add in preventive maintenance and planned upgrades.

- **Resource planning:**

Locate necessary labor, contractor work, equipment, and supplies.

- **Task allocation:**

Outsource essential duties to home teams, others to the subcontractors, with clear guidelines.

- **Schedule sharing:**

Share the draft designs with all interested parties for comments.

- **Final plan:**

Consolidate the input into a final, coordinated action plan.

- **Master schedule:**

A zone-based Alf world clock for tracking and presentation.

- **Coordination meetings:**

Make sure everyone is on the same page before shutdown.

- **Shutdown execution plan:**

Implement the agreed shut down time line and confirm.

### III.10.4 Internal setup of TSS maintenance department:

The following organizational chart illustrates the structure of the Maintenance Department, outlining the various service units and their reporting lines. It highlights the distribution of responsibilities among key maintenance functions, such as electrical, mechanical, tooling, and overhead crane services. This structure ensures efficient coordination and oversight under the leadership of the head of the maintenance department.

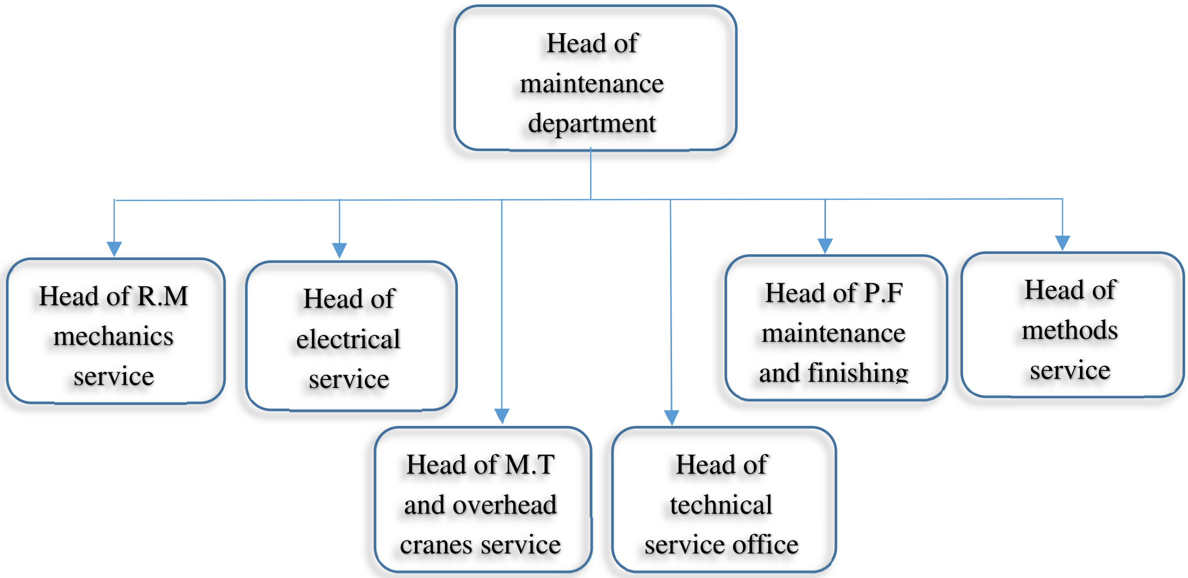


Figure III.3: Maintenance service organizational chart [4].

# III.11 The Pushing device maintenance:

## III.11.1 Systematic maintenance:

| SEAMLESS TUBE | | MTD / EEM | | | | E - DO EEM 007 PREVENTIVE MAINTENANCE SCHEDULE | | | | | | | | | YEAR: 2025 | | PAGE: 1/1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | MECHANICAL ROLLING: COMMON AREA | | | | | | | | | TZ MEC COM Bouaziz Bilal | | |
| REP | MACHINES | PERIODICITY | Personnel Number | PM Sheet Number | INPUT | January | February | March | April | May | June | July | August | September | October | November | December |
| | | | | | | 1 2 3 4 | 5 6 7 8 | 9 10 11 12 13 | 14 15 16 17 | 18 19 20 21 | 22 23 24 25 26 | 27 28 29 30 | 31 32 33 34 | 35 36 37 38 39 | 40 41 42 43 | 44 45 46 47 | 48 49 50 51 52 |
| 1 | Presentation device LP14" | M | 2 | 20 | 565 22 00 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |

| | | | | | |
|---|---|---|---|---|---|
| Number | Time scheduled in hours | M | Monthly | | |

Table III.1: Preventive maintenance schedule of the pushing device [4].

- The procedure applied within the company follows the general safety instructions and is as follows [4]:

1 -Structure

Check:

- Good overall condition;
- Condition of locking corners;
- Condition of piping.

2 - Air chamber

Check:

- No air leakage at the front and rear sides;
- No water ingress into the chamber;
- Tightness of the entire assembly.

3 - Drall and nut

- Note the wear condition of the nut;
- Move the drall along the entire length of the stroke and check for absence of stiff points.

4 - Braking chamber

- Check the effectiveness of braking;
- Tightening of the brake.

5 - Water tank

Check:

- Good overall condition;
- Fixing of the cap.

6-Reducer motor

Check:

- Tightness;

- Fixing on the body of the device;
- Tightening of the bolts.

7 - Transmission extension

Check:

- Fixing;
- Good overall condition.

8 -Freewheel

Check:

- Proper functioning;
- Oil level;
- Fixing.

9 - Device nose

Check:

- Good condition of the body;
- Proper functioning of the chuck locking mechanism;
- Fixing of the locking command cylinder (presence of pins + locking plate);
- Fixing of the two retaining pins of the locking finger (presence of nut locking plate).

### III.11.2 Corrective maintenance:

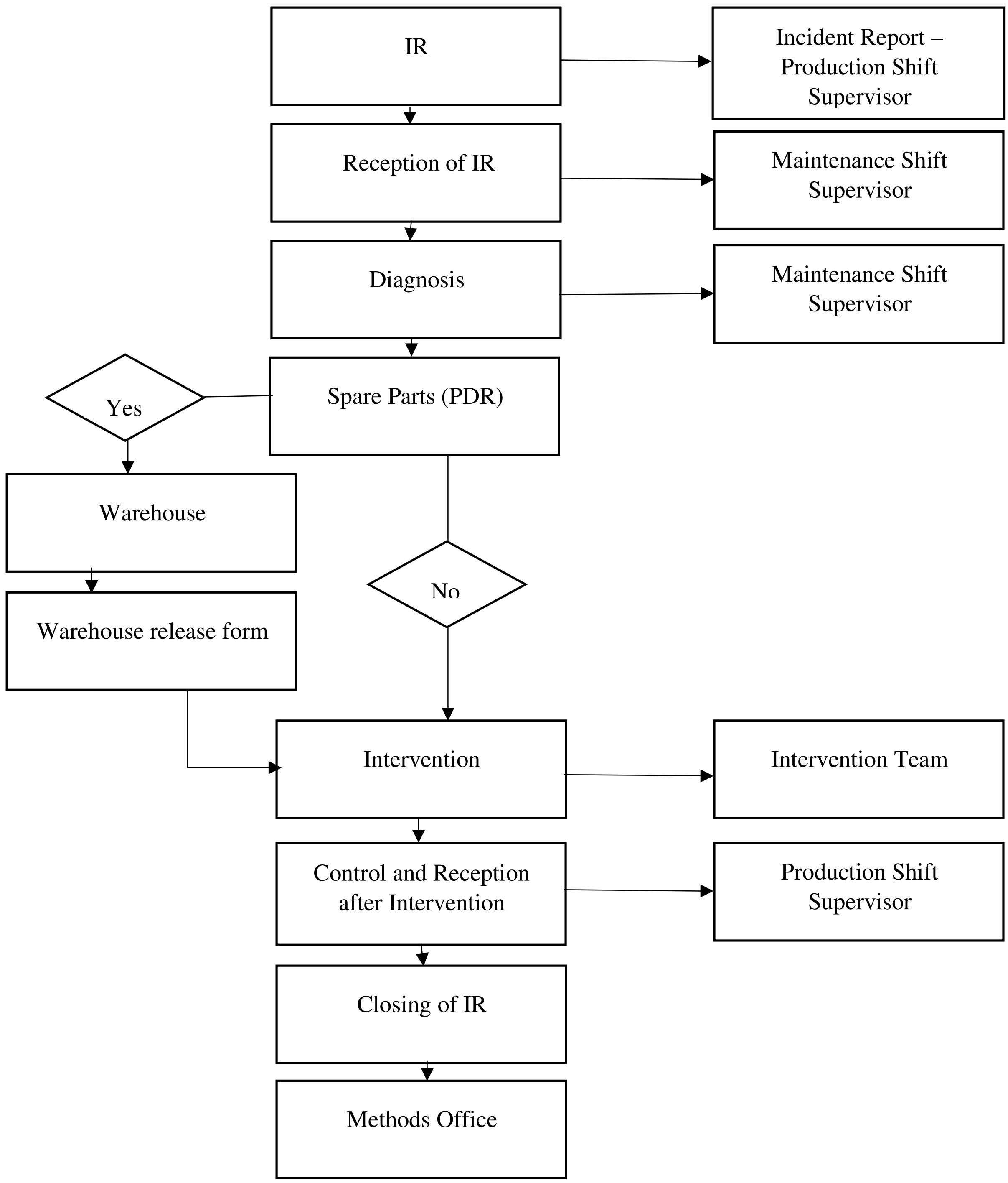


Figure III.4: Corrective maintenance process.

### III.11.3 Work order circulation:

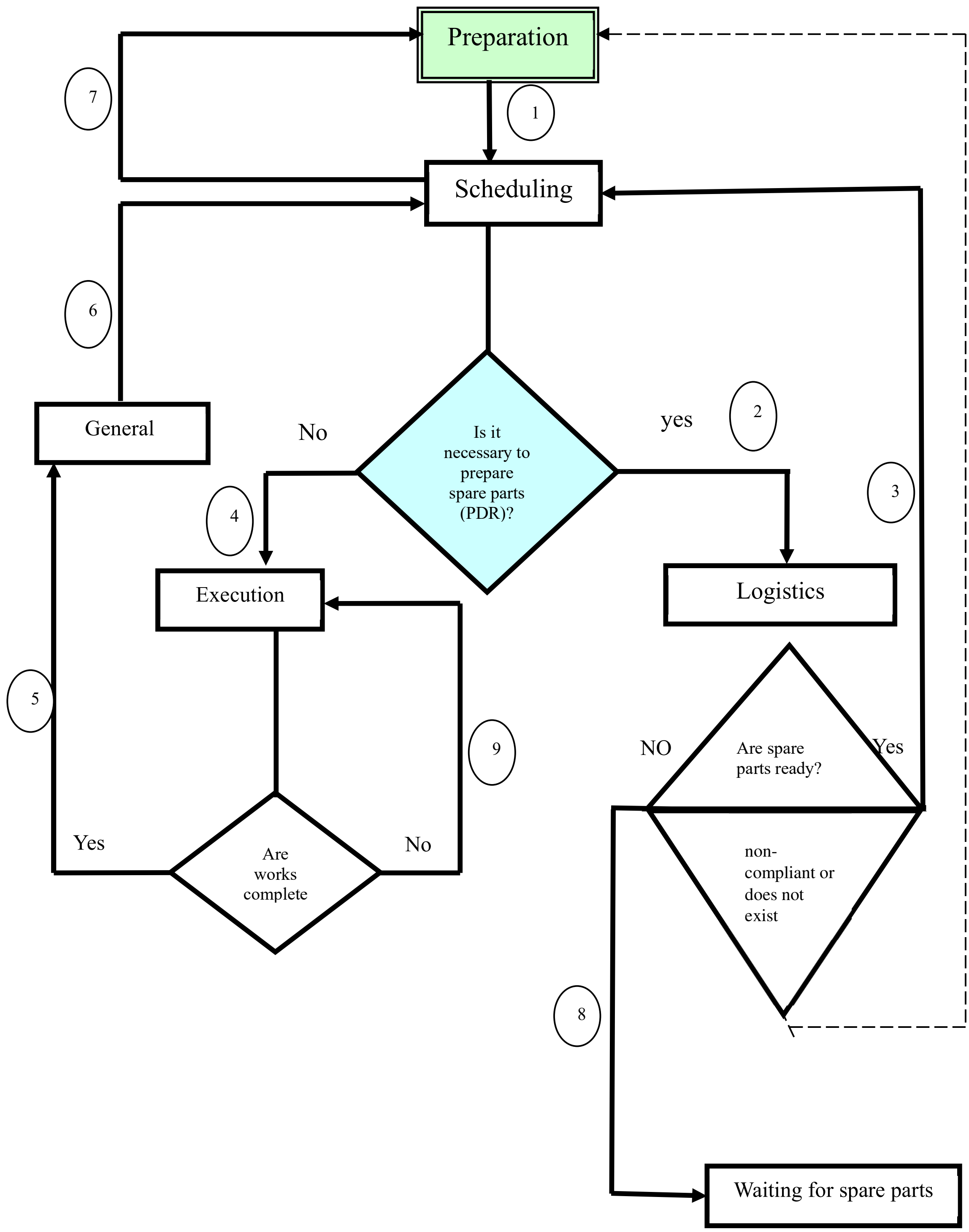


Figure III.5: Circulation of the WO [10].

# Chapter IV
# Failure analysis of the pushing device

## IV.1 Introduction:

Failure analysis is a crucial process used in maintenance management that aims to identify the root causes and failures analyze of assets. By analyzing environmental conditions as well as mechanical, electrical, or operational issues, it helps to minimize unplanned downtime, enhance operational safety, and increase equipment lifetime. In the TSS process at Sider Company, the pushing device is considered as critical equipment because it plays a significant role in guiding the blank during the rolling process. Any failure in this system can disrupt and affect the production chain and compromise product quality.

This chapter focuses on studying the reliability of the pushing device using Weibull's distribution. To figure out the main reasons behind failure and to develop a methodology that tacks into consideration both qualitative and quantitative aspects by utilizing with Weibull's analysis the Ishikawa diagram.

## IV.2 Reliability calculation of the pushing device:

Reliability is defined as the likelihood of a device fulfilling its required function under particular usage conditions and for a given duration. Its computation is as follows [8]:

### IV.2.1 Weibull's distribution:

The two-parameter Weibull distribution is highly flexible, making it suitable for modeling a large variety of data collected throughout the equipment's lifespan. It effectively accounts for varying failure rates, capturing both early-life failures (infant mortality) and those that occur later due to wear and aging. The application provides, an estimate of the mean time between failures (MTBF) of the failure population. Relations for R (t) (reliability function) and λ (t) (failure rate), with graphical representations. Additionally, the shape parameter β, which can help guide diagnostics, as its value is characteristic of certain failure modes.

- Probability density function (PDF):

$$f(t) = \frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1} e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}}, \quad \text{for } t \geq \gamma \qquad \text{.............................(1)}$$

- Cumulative distribution function (CDF):

$$F(t) = 1 - R(t) = 1 - e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}}, \quad \text{for } t \geq \gamma \qquad \text{.............................(2)}$$

- The reliability:

$$R(t) = e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}}, \quad \text{for } t \geq \gamma \qquad \text{.............................................(3)}$$

- The hazard rate:

$$h(t) = \frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1}, \quad \text{for } t \geq \gamma \qquad \text{..................................(4)}$$

- The mean time between failures :

$$\text{MTBF} = E[T] = \eta \cdot \Gamma\left(1 + \frac{1}{\beta}\right) \qquad \text{.............................................(5)}$$

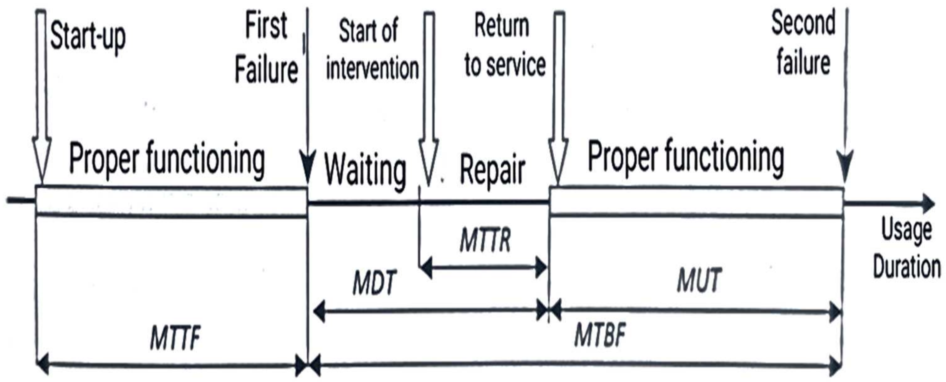


Figure IV.1: The characteristic durations of RAM [8].

- MTTF: Mean Time to first Failure.
- MTTR: Mean Time to Repair.
- MUT: Mean up time.
- MDT: Mean down time.
- MTBF: Mean time Between Failures.

From the time between failures (TBF) analysis of the pushing device, we observe:

$$MDT \ll MUT \Rightarrow MTBF \approx MUT.$$

The MDT is much smaller than MUT. Therefore, MTBF can be approximated as MUT.

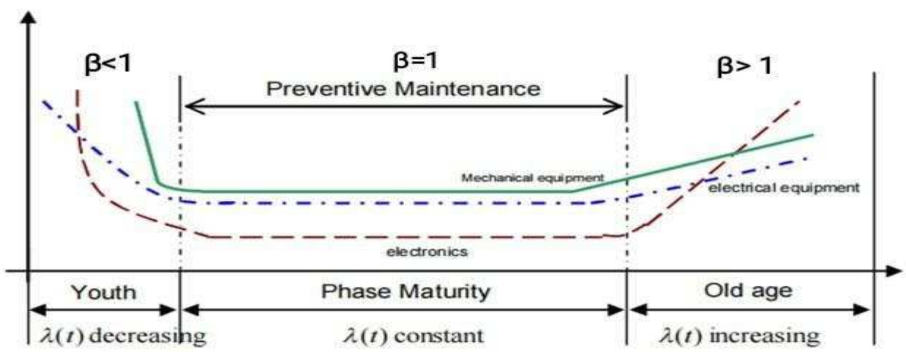


Figure IV.2: The bathtub curve [12].

## IV.2.2 KOLMOGOROV-SMIRNOV TEST:

No specific assumptions are required, the test can be applied for any sample size n. However, when n is large, it is often suitable to gather the data into classes and instead use the chi-squared $\chi^2$ test. The basic premise is to contrast the observed data's empirical cumulative distribution function (ECDF) with the theoretical cumulative distribution function (CDF). The maximum point-wise deviation between these two functions is measured in this test [13]:

$$Dni = |\mathscr{F}(t) - F(t)| \quad \text{.......(9)}$$

$\mathscr{F}(t)$: Empirical distribution function.

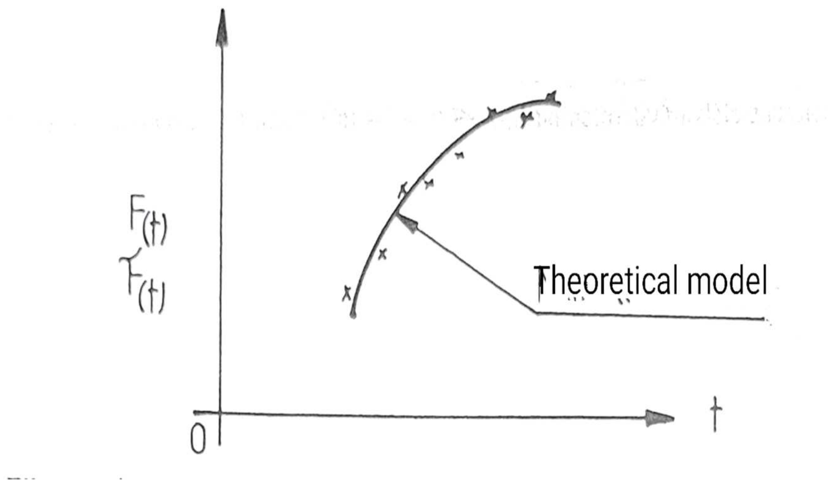


Figure IV.3: Theoretical cumulative distribution function graph [13].

It can be estimated using the method of mean ranks [13]:

$$\mathfrak{F}(ti) = \frac{i}{n+1} \quad \text{.......(10)}$$

F(t) : Theoretical function.

It can be shown that Dn = Max |$\mathscr{F}$(t) −F (t)| follows a distribution that depends only on *n*, and is expressed as [13] :

$$P[\text{Max} \, |\mathfrak{F}(t) - F(t)| < D_{n,\alpha}] = 1 - \alpha \quad \text{.....................................(11)}$$

The value of Dn, α is provided in the Kolmogorov-Smirnov table.

Dn >Dn, α, The theoretical model's null hypothesis is not accepted.

To accept the model, the empirical values $\mathscr{F}$(t) must lie within a confidence band around F (t), assuming a theoretical cumulative distribution F (t). The construction of this confidence band is as follows [13]:

$$F(t) - D_{n,\alpha} \leqslant \mathfrak{F}(t) \leqslant F(t) + D_{n,\alpha} \quad \text{.....................................(12)}$$

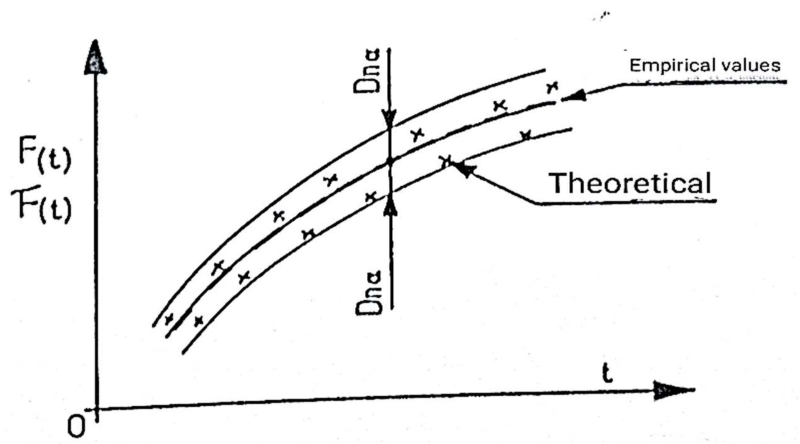


Figure IV.4: Theoretical cumulative distribution function and empirical cumulative distribution function graphs [13].

### IV.2.3 The pushing device case:

The estimation of weibull distribution parameters in this case of pushing device.

- Median rank formula [11]:

$$P_f(t_i) = (t_i - 0.5) / N \quad (6)$$

- Natural logarithm of time to failure [11]:

$$X = \ln(t_i) \quad (7)$$

- Double logarithmic transformation of the unreliability function [11]:

$$Y = \ln[\ln(1/(1-P_f))] \quad (8)$$

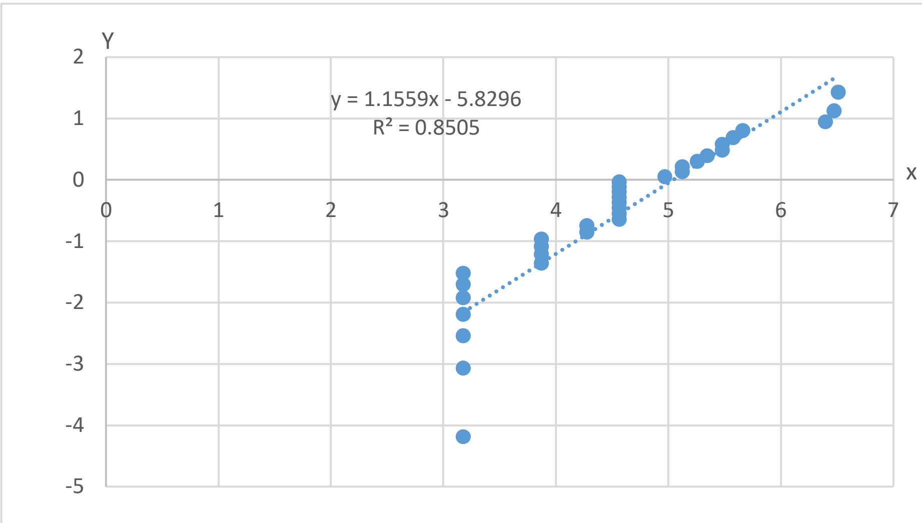


Figure IV.5: Scatter plot with a linear regression line.

In Figure IV.5 graph, there is a linear relationship between variables X and Y, as indicated by the regression line that as X increases, Y also increases, with a slope of approximately 1.15. The coefficient of determination ($R^2 = 0.85$) means that 85% of the variation in Y is explained by X, showing acceptable fit of the model. To summarize, X can be a reliable predictor of Y in this data set.

| The line Equation y | Shape parameter β | Scale parameter η | Location parameter γ | MTBF |
|---|---|---|---|---|
| 1.1559x−5.8296 | 1.15 | 155 | 0 | 147 |

Table IV.1: Weibull distribution parameters and MTBF for the pushing device.

β ≈ 1 indicates a moderate time-dependent increase in failure rate.it can be considered that the pushing device is in its maturity period, or at the beginning of old age. In the first case, the reliability is optimal and consistent, the failures are resulting from usage. They are predictable and therefore require preventive maintenance.

| Sample size n | Significance level α | Calculated test statistic Dmax | Critical value Dn,α | Comparison |
|---|---|---|---|---|
| 33 | 0.05 | 0.00272603 | 0.52 | Dmax <Dn,α |

Table IV.2: kolmogorov-smirnov test results.

Dmax <Dn,α, and that's mean the null hypothesis is verified. The sample distribution and reference distribution are not significantly different at the 5% level of significance.

Figure IV.6, is a cumulative distribution function (CDF) graph as a function of time between failures (TBF). The curve starts at F(0)=0 meaning at time zero, the probability of failure is zero .But As time increases, F(t) increases and approaches 1, indicating that eventually, almost all units will have failed.

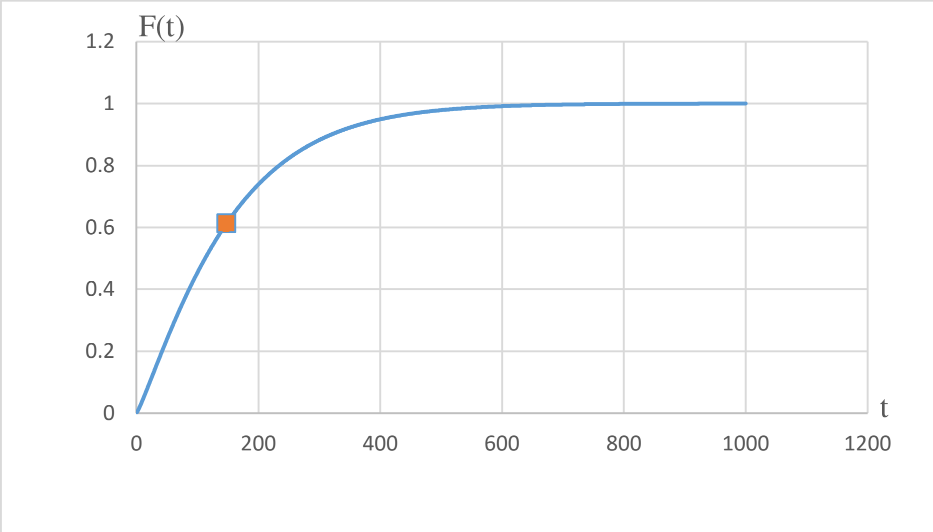


Figure IV.6: Cumulative distribution function graph.

In the MTBF (Mean Time Between Failures) the cumulative probability F(t) is about 0.61, meaning that approximately 61% of units have already failed by the time they reach the MTBF. Only about 39% of units are still functioning at this average failure time. This demonstrates that the MTBF is a statistical average rather than a minimum guaranteed lifetime for the equipment.

Figure IV.7, depicts reliability function R (t) as a function of time between failures (TBF). However, as time progresses, the probability of failure increases. This means that the longer the equipment operates, the higher the probability of failure becomes.

Regarding the MTBF (Mean Time Between Failures), we note that the reliability at this point is approximately 39%. This means that only 39% of the units are expected to operate without failure up to the MTBF value, while the remaining 61% are likely to fail before reaching that time.

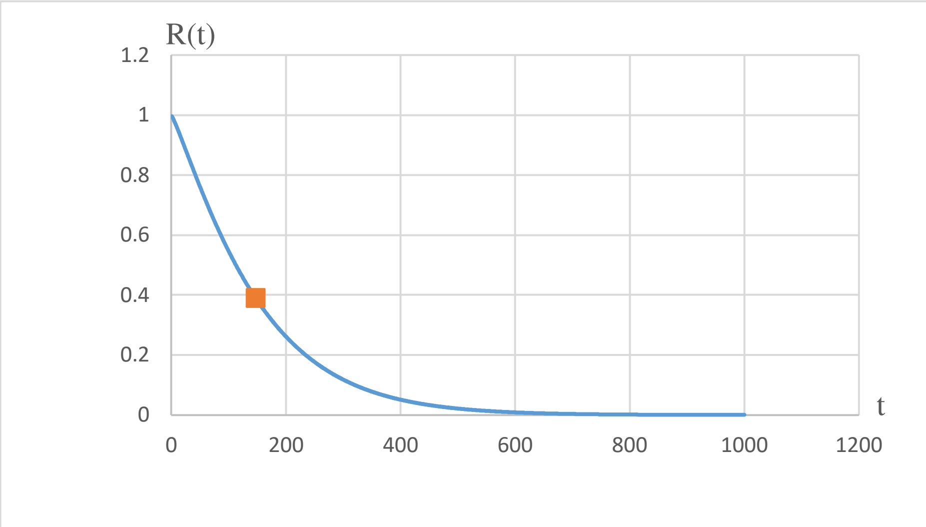


Figure IV.7: The reliability diagram.

Figure IV.8, shows the probability density function graph as a function of time between failures (TBF). We observe that the probability density function graph is increase until reaching the greatest value of (0.005) than its start decreasing with time. The peak of the curve represents the most likely time between failures (the mode of the distribution), not the mean.

In this graph, the MTBF is shown at a TBF where the PDF value is about 0.003, which is past the peak of the curve. The MTBF does not indicate the most likely period of failure (the peak). Instead, MTBF is considered as the average TBF and is generally positioned to the right of the peak on distributions, like this one.

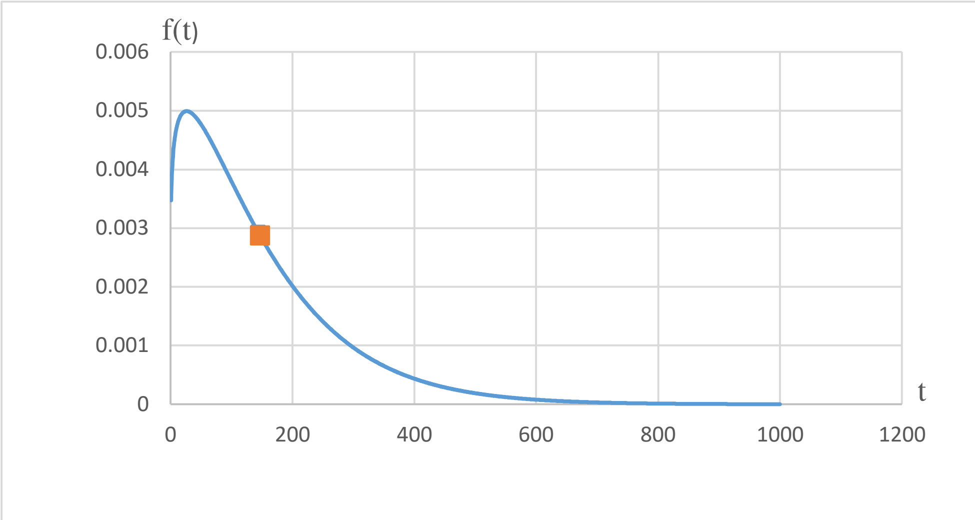


Figure IV.8: Probability density function graph.

## IV.3 Locking finger failures analysis:

The axial retention of the mandrel is ensured by a pneumatically actuated locking finger located inside the sleeve. It is triggered via a piston housed in a sealed chamber, enabling secure mechanical engagement. This technology ensures the mandrel's stability during positioning and the beginning stages of the rolling operation. At the end of the rolling process, the workpiece is withdrawn by reversing the hydraulic movement, assisted by the piston that pushes the piece out of the furnace [4].

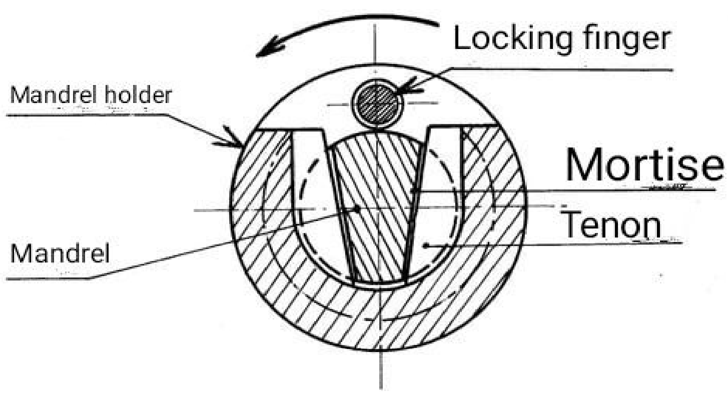


Figure IV.9: The locking finger position [4].

Determining the pressure required to engage the locking finger, based on [4]:

- Temperature (T);
- Initial pressure ($P_0$);
- Piston stroke (x);
- Initial volume ($V_0$);
- Cross-sectional area of the piston (S).

$$P = \frac{P_0 \cdot V_0}{V_0 - S \cdot x} \qquad \text{……………..……………………………………(13)}$$

### IV.3.1 Locking finger downtime analysis:

The graphic figure IV.10, indicates that higher value of downtime occurred at a specific period that can be related to production schedule or climate conditions.

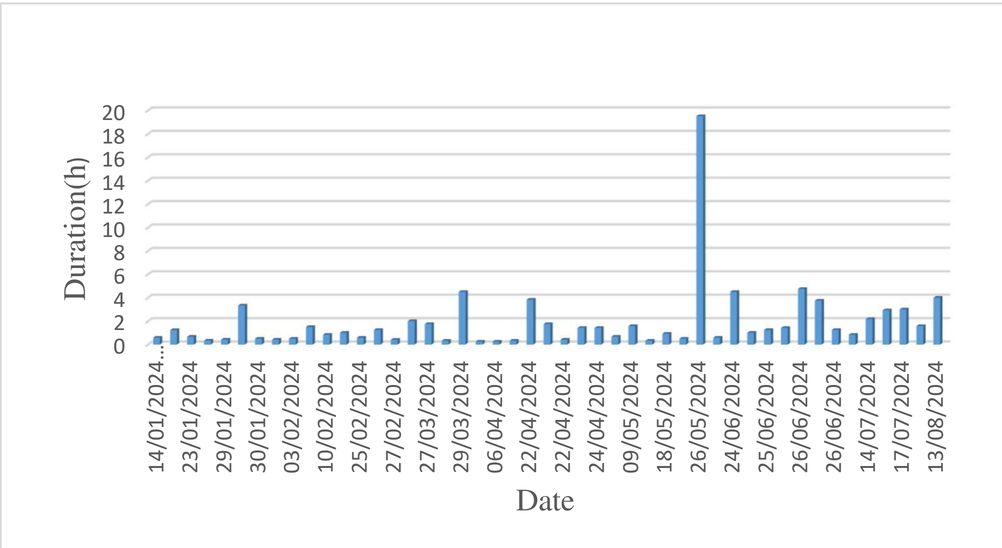


Figure IV.10: Downtime graph.

The graphic figure IV.11, indicates that mechanical components are responsible of higher value of downtime.

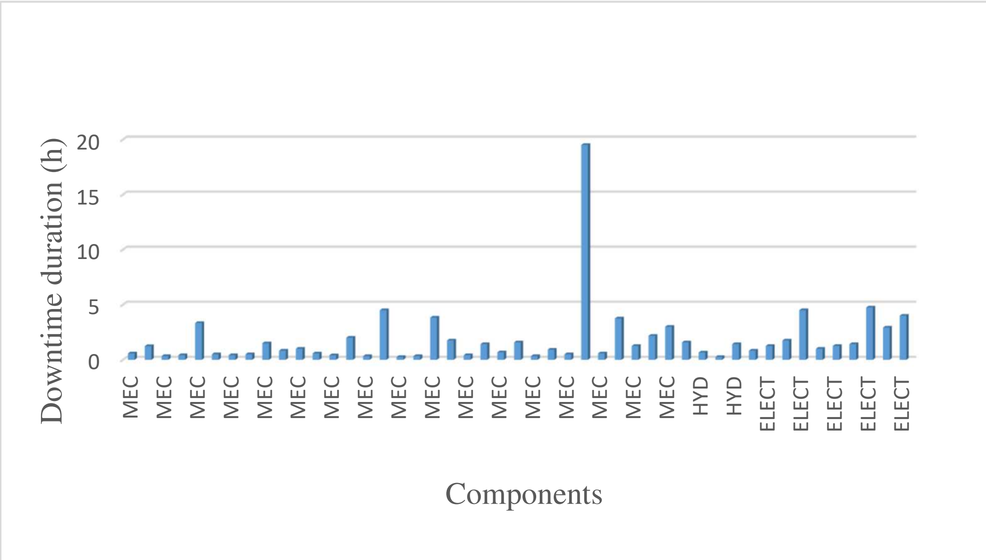


Figure IV.11: Components failures graph.

Figure IV.12 indicates that the locking finger failure causes the highest downtime.

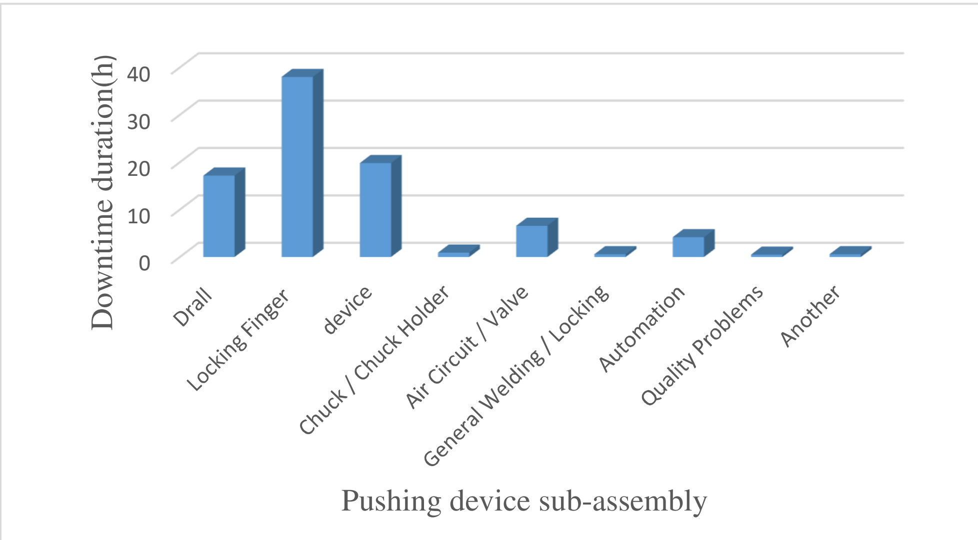


Figure IV.12: The pushing device sub-assembly graph.

Figure IV.13 indicates that the locking finger repair needs the highest duration.

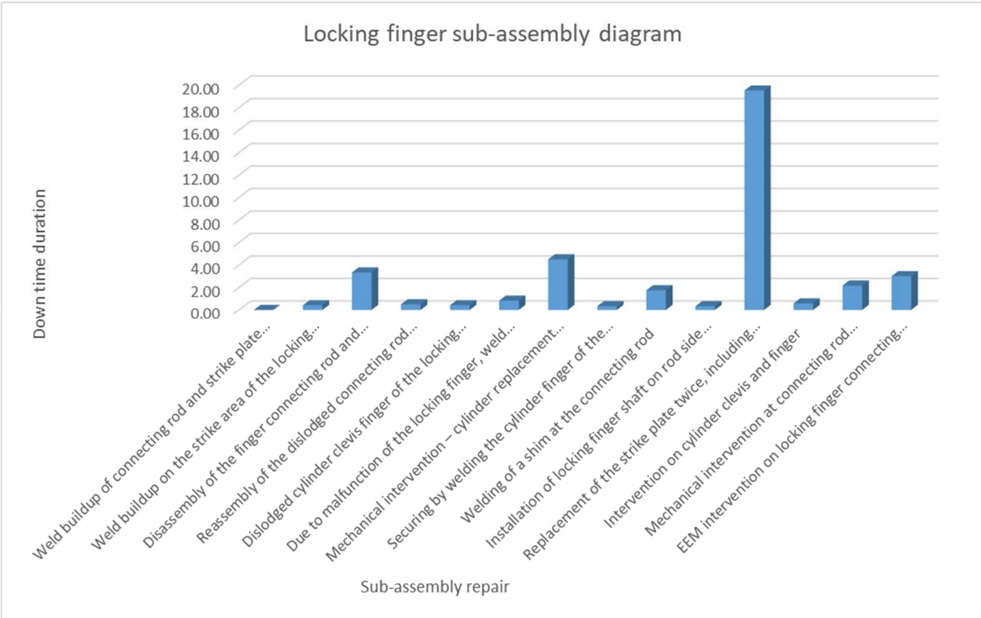


Figure IV.13: Locking finger sub-assembly graph.

The graphs shows the downtime rate as a function of duration, components, the pushing device sub-assembly, and the locking finger sub-assembly. It is observed that the highest rate of failures is due to mechanical issues. Upon deeper analysis, it is emphasized that the major part of these failures concerns the locking finger, which is a sub-assembly of the pushing device. Therefore, the locking finger is identified as the main component of the pushing device's downtime, primarily due to frequent issues with the failure morphology of the connecting rod.

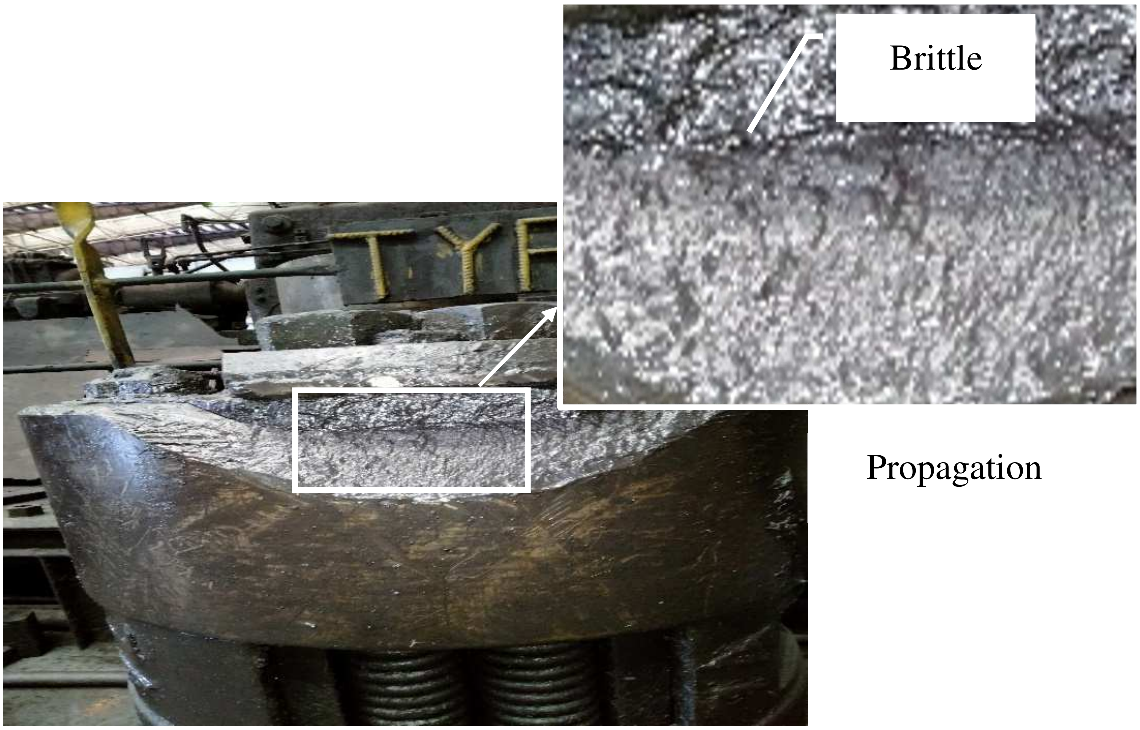


Figure IV.14: Failure morphology [4].

In the figure IV.14, the morphology of the failure surface depicts a semi-brittle mode, which is likely due to repeated mechanical shocks or heavy banding loads. The close-up shows areas of the metal that have become worn and rough. This kind of damage usually occurs when the strike plate is subjected to sudden or excessive loads, leading to material failure. This might explain the high failure rate of the locking finger. Regular inspection and maintenance are crucial for preventing such failures and ensuring reliable operation.

Figure IV.15: The locking finger position [4].

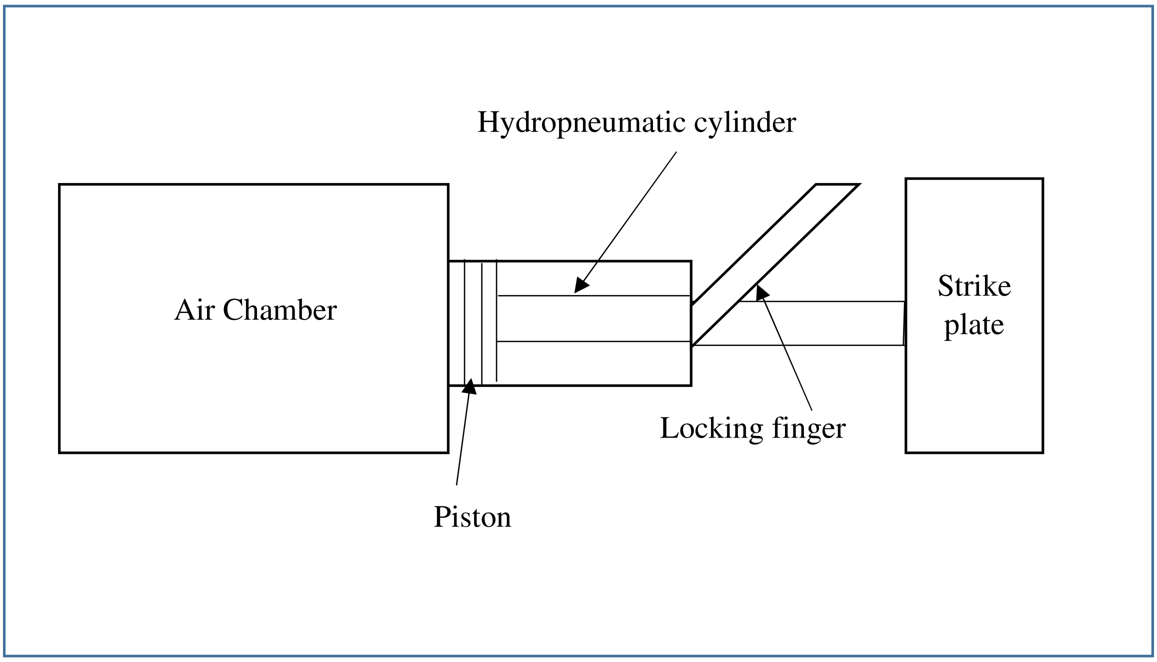


Figure IV.16: Illustrative diagram of the locking finger position.

### IV.3.2 The Ishikawa diagram:

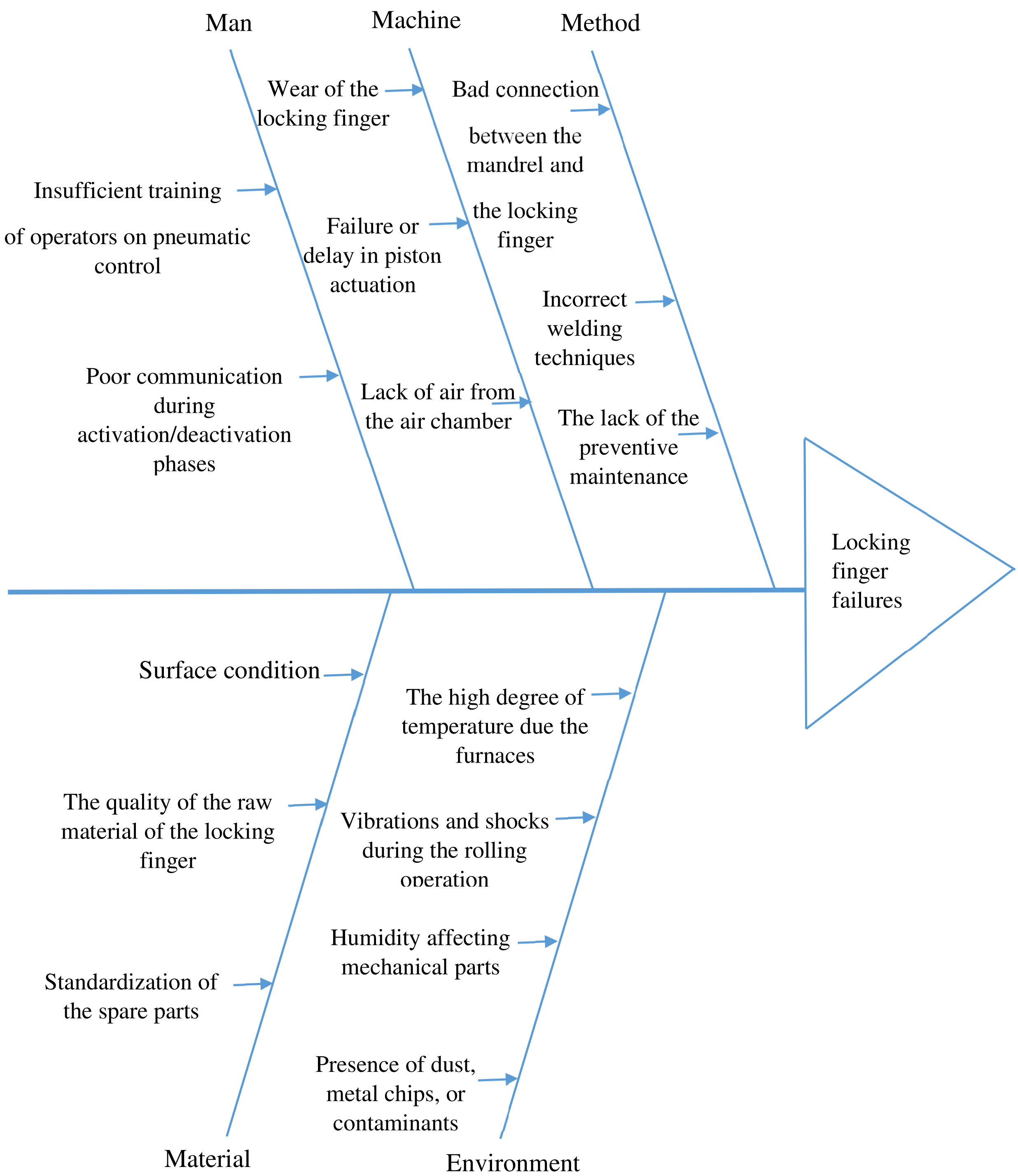


Figure IV.17: Ishikawa diagram.

### IV.3.3 Proposed improvements to reduce failure rate and enhance locking finger performance:

- **Enhance material properties:**

Use durable, fatigue-resistant materials for longer component life and reliability.

- **Install pressure and position sensors:**

Integrate sensors to monitor system pressure and detect misalignments or early signs of malfunction.

- **Ensure routine cleaning:**

Maintain cleanliness of the locking mechanism to prevent dust, debris, or corrosion-related issues.

- **Redesign contact surfaces:**

Optimize the geometry of contact zones to distribute mechanical stresses more evenly, thereby reducing localized wear and potential failure points.

- **Ensure precise Alignment:**

Improve guiding systems and calibration procedures to ensure proper alignment between the locking finger and mandrel.

- **Apply standardized welding procedures:**

Use certified welding processes and conduct post-weld inspections to prevent distortion or weak joints caused by over-welding.

- **Implement root cause analysis (RCA) :**

After each failure, conduct RCA to identify and eliminate the root cause, preventing recurrence of similar issues.

- **Enhance the surface condition:**

To reduce friction and wear, improve performance, and extend the service life of the locking finger, while ensuring its reliability and precision during operation.

# Conclusion

## Conclusion:

The focus of this study was on the pilger rolling process used in the production of seamless tubes. Among the critical components of this process is the pushing device, which ensures both the horizontal return and the rotational positioning of the blank and mandrel between rolling phases. Like all mechanical systems, the pushing device is subject to failures that can result in production interruptions, additional costs, and compromised product quality. Through failure rate analysis, several components of the pushing device such as the drall, air circuit, Chuck…, were identified as frequent sources of downtime. However, the locking finger was found to be the most failure-prone component, significantly affecting system reliability and process efficiency.

Failure analysis has been conducted in order to identify and study the reliability and failure of the pushing device. The adopted methodology contains Weibull's distribution that leads to determine the reliability of this equipment. The second part of this study presents a qualitative analysis method that allows the identification of the locking finger as the main component causing the highest level of downtime. To address these issues and improve the performance of the pushing device, the following improvements are recommended:

- Using pressure and position sensors;
- Use a high-precision alignment component;
- Enhanced training for operators and maintenance technicians;
- Application of Root Cause Analysis (RCA) for long-term problem resolution;
- Enhance the surface condition.

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