



The People's Democratic Republic of Algeria
Ministry of Higher Education and Scientific Research
Faculty of Applied Sciences
Affiliated with the Department of Mechanical Engineering



A this has been submitted to obtain a

Master's Diploma

Field: Mechanical Engineering

Specialization: Mechanical Manufacturing and Production Engineering

THEME

Design and Development of a Semi-Automatic Chain Link Fence Machine

Presented and defended by:

HADJAIDJI AYOUB & GHAMRI MED FARES

Defended On: Jun 2026

KHALFI MAHDI	Kasdi Merbah University – Ouargla	President
ABDELKARIM MOURAD	Kasdi Merbah University – Ouargla	Examiner
DERNOUNI MOHAMED	Kasdi Merbah University – Ouargla	Supervisor

Academic Year: 2025 –2026

Thanks and appreciation

We thank God Almighty for giving us good health and enabling us to start and finish this message.

*First and foremost, I would like to express my sincere gratitude to Prof. **Dr. DERNOUNI MOHAMED** for his continuous supervision, invaluable guidance, unwavering support, and constructive advice throughout the completion of this work. His expertise, encouragement, and dedication have been of great importance to the success of this project. I deeply appreciate his efforts and extend my heartfelt thanks and respect.*

*We would like to thank **Dr. ABDELKARIM MOURAD**, Professor at the University of Kasdi Merbah Ouargla, for dedicating his time to reviewing our manuscripts and agreeing to chair the evaluation committee.*

*We also express our gratitude to **Dr. KHALFI MAHDI**, lecturer at Kasdi Merbah University of Ouargla, for the honor of his participation in our evaluation committee.*

*We would also like to express our sincere gratitude to. **Mr. RACHID INDUSTRIAL** Workshop for its valuable support and assistance throughout the completion of this project. We highly appreciate the practical guidance and advice provided, which contributed significantly to the development of this work and the improvement of its outcomes. Our heartfelt thanks go to them for their cooperation and support.*

We would like to express our gratitude to all of our teachers for their generosity and tremendous patience despite their academic and professional workload.

Hadjaidji Ayoub And Ghamri Med Fares

Dedications

*Praise be to **Allah** who guided us and helped us complete this work, for Him alone is all praise and thanks for His countless blessings and for His guidance in accomplishing this memorandum.*

***My dear father**, I hope that with this achievement, I have compensated you, even if just a little, for the sweat of your brow and your weary face, which has long been troubled by worries, sadness, and the bitterness of days, until you see the fruits of your labor blossom.*

*As for **my dear mother**, with your prayers, my name was inscribed on the shawl and became a reality.*

I say to you, my beloved, you under whom lies a paradise as wide as the heavens and the earth, whose prayers open the gates of heaven, by your grace the years of drought have eased, and iron has softened before your will. I bow to you; you who withered the flower of your youth to make us bloom.

*And to those who have greatly contributed to encouraging and motivating me, from whom I have learned perseverance and diligence, to my "**brothers and sisters**," especially to my sister and companion, "**Nourhane, Feryal**" who has supported me throughout my life.*

*To the **Doctor** who eased my loneliness and relieved my fatigue with just a word, **thank you** for being the light that never fades in my life. No matter how much I write to you, I will never be able to describe your kindness and support toward me. You are the most beautiful part of my university journey.*

*And to **my friends** and companions along the years, and to everyone who has been a support and a pillar for me on this journey, especially **my steadfast friends (Imad, Younes, Nidal, Islam, Fares, Chouaib, Moutassim, Ramzi, Elhadj, Abdelkader, Messoud, Khaled, Ahmed, Houssam, Walid, Abdelmouz)**, I extend my sincere gratitude and appreciation to you all. If it weren't for your kindness and support, after God's grace, I wouldn't be where I am today.*

In the end, we ask God to grant everyone success in what is good.

HADJAIDJI AYOUB

The journey was not short, and it was never meant to be easy. The dream was far away, and the road was filled with challenges, sacrifices, patience, and endless effort. Yet, with faith, determination, and the support of those I love, I finally made it.

*I dedicate my graduation to the soul of the man whose name I proudly carry, the one who removed the thorns from my path and paved the way for knowledge and ambition, **my beloved father.***

May Allah grant him the highest place in Paradise. Even though you are no longer by my side, your presence continues to guide me every single day. Your sacrifices, your values, and your love remain deeply rooted in my heart, and this achievement would never have been possible without everything you gave for me.

*To the hidden hand that supported me through every difficult moment, and to the one who endured my pain, weakness, and struggles with endless patience and unconditional love, **my beloved mother.***

You are my source of strength, my comfort, and the light that brightens my darkest days. Your prayers have always been the secret behind my success, and your support has given me the courage to continue whenever life became difficult. May Allah protect you and reward you for everything you have done for me.

*To everyone who contributed to encouraging and motivating me, and from whom I learned patience, perseverance, and determination, especially **my brothers and my sister,** thank you for standing beside me and believing in me throughout this long journey.*

*To **my friends and companions, (Ayoub, Aymen, Ahmed)** who shared with me unforgettable moments, supported me during difficult times, and made this journey more meaningful and memorable, I express my deepest gratitude and appreciation.*

Finally, I thank everyone who has been part of my academic journey, whether through support, advice, encouragement, or even a simple kind word that gave me hope and motivation to move forward.

May Allah grant us success, happiness, and guidance in all the steps of our lives.

Ghamri Mohammed Fares

Abstract:

This project focuses on the design and production of a semi-automatic machine for manufacturing chain link fences, with the objective of balancing operational efficiency and economic cost while augmenting the labor rather than displacing it. The apparatus operates on the basis of helical wire formation, utilizing a mechanical system powered by an electric motor and a reducer to provide requisite torque and stability throughout production while ensuring dimensional precision and uniformity in the shape of the apertures. In contrast to the manual approach, which demands considerable effort and may exhibit inconsistencies in quality, the suggested machine enhances working conditions and boosts productivity while preserving the worker's involvement in operation, oversight, and standard calibration. It serves as a viable alternative to fully automated, expensive, and intricate machinery, facilitating the generation of new employment opportunities, the enhancement of technical skills, and the support of small and medium-sized enterprises, while retaining the potential for future advancements in automation without disregarding the human component.

المخلص

يتمحور هذا المشروع حول تصميم وتصنيع آلة نصف آلية لإنتاج السياج المعدني (Chain Link Fence) ، بهدف تحقيق توازن بين الكفاءة التشغيلية والتكلفة الاقتصادية مع دعم اليد العاملة بدل الاستغناء عنها. تعتمد الآلة على مبدأ التشكيل الحلزوني للأسلاك باستخدام نظام ميكانيكي مدعوم بمحرك كهربائي لضمان توفير العزم اللازم واستقرار عملية الإنتاج، مع تحقيق دقة في الأبعاد وتجانس في شكل الفتحات. وعلى عكس الطريقة اليدوية التي تتطلب جهداً كبيراً وتفتقر أحياناً إلى الانتظام في الجودة، فإن الآلة المقترحة تحسّن ظروف العمل وترفع الإنتاجية مع الحفاظ على دور العامل في التشغيل والمراقبة وضبط المعايير. كما أنها تمثل بديلاً مناسباً للآلات الآلية الكاملة مرتفعة التكلفة والمعقدة، حيث تتيح خلق فرص عمل جديدة، وتنمية المهارات التقنية، ودعم المؤسسات الصغيرة والمتوسطة، مع إمكانية تطويرها مستقبلاً دون إقصاء العنصر البشري.

Table of contents

GENERAL INTRODUCTION	1
-----------------------------------	----------

Chapter I: Literature Review

I.1 GENERAL INTRODUCTION TO METAL FENCING WIRE’S GENERAL INTRODUCTION TO METAL FENCE WIRES....	4
I.2 HISTORICAL BEGINNINGS: THE STAGE OF HAND WEAVING AND EARLY MECHANIZATION HISTORICAL BEGINNINGS: THE STAGE OF HAND WEAVING AND EARLY MECHANIZATION	4
I.2.1 Hand weaving of the metal fence.....	4
I.2.2 Charles Barnard's (1844) invention of the engineering simulation for weaving machines.....	4
I.2.3 Technical Specifications of the Barnard Machine	5
I.3 TECHNOLOGY TRANSFER TO THE UNITED STATES AND PRODUCTIVITY DEVELOPMENT THE TRANSFER OF TECHNOLOGY TO THE UNITED STATES AND THE DEVELOPMENT OF PRODUCTIVITY	5
I.3.1Page Woven Wire Fence.....	5
I.3.2 The Transition in Torsional Dynamics and Automatic Coupling.....	5
I.4 ANALYSIS OF US652431A PATENT AS A MODEL FOR MECHANICAL DEVELOPMENT ANALYSIS OF PATENT US652431A AS A MODEL FOR MECHANICAL DEVELOPMENT.....	6
I.4.1 Overview of Patent US652431A	6
I.4.2Machine components according to the patent.....	6
I.5 TRANSITIONING FROM MANUAL TO SEMI-AUTOMATIC TO AUTOMATIC TRANSITIONING FROM MANUAL TO SEMI-AUTOMATIC TO AUTOMATIC	6
I.5.1 The manual phase:	6
I.5.2 The early mechanical stage (semi-automated in operations).....	7
I.5.3 Semi-automatic stage with electrical and hydraulic integration	7
I.5.4 Comprehensive Mechanical Automation.....	7
I.6. INTRODUCING MODERN CONTROL SYSTEMS AND TRANSITIONING TO SEMI-AUTOMATIC INTRODUCING MODERN CONTROL SYSTEMS AND TRANSITIONING TOO SEMI-AUTOMATIC	7
I.6.1 Integration of Synchronous Motors	7
I.6.2 Limit Switches	7
I.6.3 The Shift Toward Simple Digital Control	8
I.7. FULLY AUTOMATED MACHINES AND COMPUTER CONTROL FULLY AUTOMATED MACHINES AND COMPUTER CONTROL.....	8
I.7.1 Integration of Advanced Programmable Control Systems (CNC/PLC).....	8
I.7.2 Integration of Multiple Ax’s and Feed Automation	8
I.7.3 An example from recent design studies	8

I.8. COMPONENTS OF THE MODERN METAL FENCE MANUFACTURING MACHINE COMPONENTS OF THE MODERN METAL FENCE MANUFACTURING MACHINE.....	9
I.8.1 Mechanical Components.....	9
I.8.2 Power and Motion System.....	9
I.8.3 Control and Sensor System.....	9
I.9. STEPS FOR REGULAR AND PREVENTIVE MAINTENANCE OF THE METAL FENCING MACHINE	9
I.9.1 Daily and Weekly Maintenance.....	9
I.9.2 Monthly and Quarterly Maintenance	10
I.9.3 Corrective and Developmental Maintenance.....	10
I.10 CONCLUSION.....	10

Chapter II: Theoretical Study of a Wire Mesh Manufacturing Machine

II.1 THEORETICAL INTRODUCTION	12
II.2 THE GENERAL STUDY OF THE PROJECT.....	12
II.2.1 Definition of the industrial problem	12
II.2.2 Project objectives.....	14
II.2.3 Methodology.....	14
II.2.4 The required technical specifications for the machine	15
II.3 DEFINITION OF BASIC CONCEPTS.....	15
II.3.1 The woven metal fence.....	15
II.3.2 The metal wire	16
II.3.3 The mechanical weaving of metal wires	17
II.3.4 The semi-automatic machine in manufacturing	17
II.4 THE IMPORTANCE OF THEORETICAL STUDY	17
II.4.1 Building comprehensive scientific understanding.....	18
II.4.2 Support design and reduce errors	18
II.4.3 Improving efficiency and reducing costs.....	18
II.4.4 Product quality assurance and development potential.....	18
II.5 CONTROL THEORY, AUTOMATION, AND MOTION SYSTEMS.....	18
II.5.1 Motion systems.....	18
II.5.2 Dynamic control	18
II.5.3 Industrial control systems	19
II.6 DYNAMIC ANALYSIS AND VIBRATIONS	19
II.6.1 multi-axis system analysis	19

II.6.2 Dynamic stability.....	19
II.6.3 Mathematical modeling of vibrations.....	20
II.7 POWER AND ENERGY CALCULATIONS	20
II.7.1 Formation strength calculations.....	20
II.7.2 Energy consumption	20
II.8 MECHANICAL STRUCTURE DESIGN.....	20
II.8.1 Stress analysis.....	20
II.8.2 Selection of materials and treatments	20
II.9 QUALITY AND SAFETY STANDARDS	21
II.9.1 Quality standards and control	21
II.9.2 Engineering and safety standards	21
II.10 INDUSTRIAL STANDARDS (LES NORMS) AND ISO STANDARDS	21
II.10.1 The concept of industrial standards and their importance	21
II.10.2 The nature of the ISO organization and its standardization role	21
II.10.3 The standards applied in the project and their technical applications	22
II.10.4 Material quality standards (ASTM A116).....	22
II.10.5 The overall impact of applying the standards on the project.....	22
II.11 WORKER SAFETY MEASURES AND PREVENTION OF OCCUPATIONAL HAZARDS.....	23
II.12 CONCLUSION	23

Chapter III: Components and Conception of Fence Making Machine

III.1 INTRODUCTION.....	51
III.2 THE CAREER PLAN.....	51
III.2.1 Analysis of Input System:	51
III.2.2 Processing Units Processing Units:.....	52
III.2.3 System Outputs and Losses:.....	52
III.3 GEOMETRIC ANALYSIS FOR SYSTEM SELECTION	52
III.3.1 Evaluating Cost-Effectiveness:	52
III.3.2 Productivity efficiency and quality assurance:.....	53
III.3.3 Simple and reliable technology Reliability and ease of use:.....	53
III.4 LOOKING INTO THE HUMAN-MACHINE INTERACTION SYSTEM	54
III.4.1 How to divide up work assignments:	54
III.4.2 The scientific mathematical basis (optimization problem):	54
III.5 FINDING OUT HOW BIG THE MESH SHOULD BE	55

III.5.1 Analytical engineering for the fence's opening the analytical geometry of the opening in the fence:	55
III.5.2 Criteria for establishing measures	56
III.5.3 The basic design variables.....	56
III.5.4 Geometric equilibrium analysis	57
III.6 MECHANICAL DESIGN.....	59
III.6.1 General definition of the mechanical structure	59
III.6.2 Analysis of loads and stresses affecting the structure	59
III.7 CHOOSING MATERIALS	60
III.7.1 Electric Motor	60
III.7.2 Gearbox / Speed Reducer	61
III.7.3 Cooling liquid pump.....	62
III.7.4 The helical mold for wire shaping.....	63
III.7.5 The ruler	65
III.7.6 Wire feeding and guiding system.....	66
III.7.7 Manual Cable Cutte.....	67
III.7.8-foot pedal	68
III.8 ELECTRICAL DESIGN AND CONTROL SYSTEM.....	69
III.8.1 The electrical diagram of the machine	69
III.8.2 ELECTRICAL CONTROL PANEL FOR a Semi-Automatic Chain Link Fence Machine	70
III.8.3 Distance sensor.....	71
III.8.4 Principle of operation	71
III.8.5 Device components	71
III.8.6 Industrial application.....	72
III.8.7 Sensor components.....	72
III.9 GEOMETRIC CALCULATIONS.....	73
III.9.1 Formative Forces Account	73
III.9.2 Torque calculation.....	74
III.9.3 Calculation of the required power	75
III.10 COMPONENT CLASSIFICATION AND SPECIFICATIONS	76
III.10.1 Custom-Fabricated Parts	76
III.11 ENGINEERING ASSEMBLY AND BILL OF MATERIALS:	78
III.11.1 Exploded and Fully Assembled Views.....	78
III.11.2 .Bill of Materials (BOM).....	79

III.12	MACHINE MECHANISM AND OPERATIONAL SEQUENCE.....	79
III.13	CONCLUSION.....	80
	<i>GENERAL CONCLUSION</i>	<i>81</i>
	<i>BIBLIOGRAPHY</i>	<i>82</i>

Table of figures

Chapter 1: Literature Review

Figure I-1 Chain Link Fence Machine	4
---	---

Chapter II: Theoretical Study of a Wire Mesh Manufacturing Machine

Figure II-1 Principle of Operation of the Wire Forming Mechanism.....	13
Figure II-2 The woven metal fence	16
Figure II-3 The metal wire	17

Chapter III: Components and Conception of Fence Making Machine

Figure III-1 The basic geometric dimensions of the metal fence network.....	55
Figure III-2- Strength vs Wire Diameter (d).....	57
Figure III-3 Weight vs Mesh Size (a).....	58
Figure III-4 The relationship between the mesh opening and the mold diameter	58
Figure III-5 Electric Motor	61
Figure III-6 Gearbox.....	62
Figure III-7 Cooling liquid pump	63
Figure III-8 The helical mold	65
Figure III-9 The ruler	66
Figure III-10 Wire feeding and guiding system.....	67
Figure III-11 Manual Cable Cutter.....	67
Figure III-12 foot pedal.....	68
Figure III-13 The electrical diagram of the machine.....	69
Figure III-14 A) Contact B) Disconnecter C) Thermal Relay.....	70
Figure III-15 Counter	72
Figure III-16 Proximity sensor.....	73
Figure III-17 Weaving Screw	76
Figure III-18 Winding Mandrel.....	77
Figure III-19 Cutting Mechanism.....	77
Figure III-20 Main Frame Structure.....	78
Figure III-21 Exploded and Fully Assembled Views	78

Indices

PLCs	programmable logic controllers
CNC	Computer Numerical Control
ISO	International Organization for Standardization
ASTEM	American Society for Testing and Materials
IEC	International Electrotechnical Commission
DIN	German Institute for Standardization
EN	European Standards
PPE	personal protective equipment
RPM	revolutions per minute
HZ	Hertz
AISI	American Iron and Steel Institute
55HRC	Rockwell C Hardness
D2	Cold-Work Tool Steel
H13	Hot-Work Tool Steel
BHM3-H	Digital Preset Counter
OPEX	operational expenditures
CAPEX	capital expenditures

General introduction

The industrial sector has seen a lot of growth lately because of the use of Fourth Industrial Revolution technology, especially in industrial automation, control systems, and embedded systems. Industrial automation is now a key part of making manufacturing processes faster, more accurate, and less prone to human mistake, which lowers costs and makes industries more competitive

The metal industry is one of the most important since it is directly linked to infrastructure, industrial safety, and farming. The chain-link fence is one of the most common metal items used to keep buildings and land safe. But a lot of small and medium-sized businesses still use manual or semi-traditional machinery to make this kind of fence. This makes them less productive, makes the mesh dimensions less constant, raises the risk of stress at work, and makes quality control worse.

On the other hand, industrial automation machines offer very fast and precise solutions. But they use a lot of electricity and cost a lot of money, with basic models costing approximately \$8,000 and European systems costing nearly \$60,000. Because of these prices, small workshops can't buy automated machines. This has led to the creation of semi-automatic machines that are cheap and made in the area.

Semi-automatic machines are more accurate and faster than manual machines because they feature both mechanical and electronic parts that cut down on the need for workers to get involved and make mistakes. People think that manual machines are inexpensive since their mechanical and electronic parts are basic. But they only rely on the worker, which might cause variances in the quality of the products and lengthier work hours. Research indicates that semi-automatic machines enhance product functionality and overall performance. This makes them a suitable alternative for medium-sized businesses because they are more productive and of higher quality than manual methods.

The significance of semi-automatic systems arises as a hybrid technical solution that integrates mechanical automation with direct human oversight, wherein the machine executes repetitive and labor-intensive tasks (such as bending, weaving, and cutting), while the operator is responsible for monitoring, feeding, and regulating the production pace. This paradigm strikes a good mix between performance, cost, and operational flexibility.

The major goal of this project is to come up with a workable engineering solution for making and building a semi-automatic machine that can make metal fences while keeping costs low and making it easy to use and maintain. It's apparent that manual machines make it harder

to be productive and accurate. For small and medium-sized firms, fully automatic machines are too expensive and hard to use. This work is about how to achieve a compromise between technology and economics that helps you construct a reliable machine that can be built in your area and meets market criteria for performance, quality, and worker safety.

The significance of this project arises from its pragmatic solution that integrates both technical and economic dimensions in the metal fence production sector. It helps create low-cost local options for imported industrial machines, which helps small and medium-sized workshops increase their productivity and product quality. This study also makes a useful scientific addition to the subject of developing semi-automatic machines by combining mechanical systems and semi-automatic control in a way that is easy to understand and use. The project also helps make working conditions better, lower stress at work, and assist the shift to local production and less reliance on technology, all of which are good for industrial and economic growth. The project is also very useful for engineering students because it shows how to design, analyze, and put into action industrial systems.

This study seeks to create a prototype of a semi-automatic machine for weaving metal fences that enhances productivity relative to conventional techniques by decreasing production time and enhancing operational continuity. It also wants to make the final product better by making sure that the mesh apertures are all the same size and that the dimensions are all the same, which will make the product meet technical standards better. The project also aims to lower the costs of making and running things by using simple mechanical solutions and parts that are easy to find in the area. It also aims to make the workplace better by making it easier to do the task and making it safer. The initiative also wants to make the machine more useful for businesses by making it easier to make, fix, and change to meet the needs of local workshops.

Chapter I:

Literature Review

I.1 General introduction to metal fencing wire's General introduction to metal fence wires

One of the most important wire-forming products is the woven wire fence (chain link/wire netting). This is because it is strong, has uniform holes, and can be used for a wide range of purposes, including farming, industry, and security. The woven fence is made by wrapping flexible metal wires around each other in a helical or mesh pattern to make hexagonal or diamond-shaped cells. This makes sure that the stresses are evenly spread across the whole mesh structure[01].

I.2 Historical beginnings: The stage of hand weaving and early mechanization Historical beginnings: The stage of hand weaving and early mechanization

I.2.1 Hand weaving of the metal fence

Before the middle of the 19th century, people made metal fences by hand using basic equipment. They twisted wires and wrapped them around stakes or wooden molds to make rough, uneven holes. During this time, productivity dropped a lot, and the workers' skills were almost the only thing that mattered. The fence could only be made to a certain size, and it was hard to make sure that the "eyes" (mesh) were of the same quality[01].

I.2.2 Charles Barnard's (1844) invention of the engineering simulation for weaving machines

Charles Barnard, an inventor from Norwich, England, is thought to be one of the first to mechanize the wire-weaving technique in 1844. He did this by making a machine that worked like traditional weaving machines used in the textile business.



Figure 0-1 Chain Link Fence Machine

Barnard adapted the technique of interlacing warp and weft threads to metal wires, creating a regular wire mesh used in farming as fence for fields and farms. He did this by using a system of pulleys, connecting arms, and wire-feeding motors[01].

I.2.3 Technical Specifications of the Barnard Machine

A continuous wire feeding system lets you put one wire or several wires into the weaving region at once. A group of mechanical arms that move like the "shuttle" in a loom, moving the wire over and under other threads to make knots. A mechanical system that uses the rotation of a main shaft to move the remainder of the mechanism using gears and crank-rocker rods. The Barnard machine was a big step forward from random manual manufacturing to regular mechanical weaving. This made the fence stronger and more durable and increased the amount of work that could be done compared to manual work.

I.3 Technology transfer to the United States and productivity development the transfer of technology to the United States and the development of productivity

I.3.1Page Woven Wire Fence

When wire weaving technology came to the United States, specialist companies started to arise. The most famous of these was the Page Woven Wire Fence Company, directed by J. Wallace Page. Its goal was to increase production and turn the product into an economically viable commodity. This firm concentrated on inventing machines that could weave vast areas of crosswire fencing faster while yet keeping the gaps the same size and the wire connections strong[02].

I.3.2 The Transition in Torsional Dynamics and Automatic Coupling

Between 1900 and 1910, during the start of the twentieth century, important patents were filed that dealt with making the process of twisting and tying wires better. One of these inventions, by William Edenburn, dealt with the problem of making hexagonal and diamond eyes with more mechanical accuracy. These new ideas were all about ways to mechanically coil the wire around itself and other wires, which meant less work for people and made the system closer to being fully automated.

I.4 Analysis of US652431A Patent as a Model for Mechanical Development

Analysis of Patent US652431A as a Model for Mechanical Development

I.4.1 Overview of Patent US652431A

An example of a metal fence-weaving machine from the early 1900s is US652431A. It displays a machine that does all three of these things: feeds wire, makes eyes, and cuts automatically. The idea shows a clear improvement in mechanical design by using rotating shafts, cams, and swinging arms to make sure that the wire and the tools for shaping it move at the same time[02].

I.4.2 Machine components according to the patent

- Wire feeding unit: It controls how fast the wire comes in and how much strain is put on it.
- Forming Mechanism: Uses guided channels and rollers to bend the wire into a diamond or helical shape.
- Twisting and binding mechanism: It makes sure that one coil overlaps the other correctly and ties them together at the spots where they meet.
- Cutting system: It cuts the fence into the right lengths or makes rolled edges to finish the edges.

This design shows how a machine that only duplicates weaving movements has changed into a machine that combines feeding, shape, binding, and cutting into one system that can do all of these things many times.

I.5 Transitioning from manual to semi-automatic to automatic

Transitioning from manual to semi-automatic to automatic

I.5.1 The manual phase:

- The worker uses pliers and rudimentary molds to completely form and fix the wire.
- Changing the size of the eyes depends on how well you can see and your own skills.
- Productivity is low, and there are a lot of mistakes in dimensions and repetition[03].

I.5.2 The early mechanical stage (semi-automated in operations)

Barnard's invention and those that came after it changed some duties into mechanical movements powered by steam engines or physical labor. However, the worker still had to do the adjusting, stopping, and monitoring. This period can be called the start of "partial automation," when people only had to give general instructions and feed the machine, while the machine did the more complicated, repetitive tasks like weaving and twisting.

I.5.3 Semi-automatic stage with electrical and hydraulic integration

From the 1970s to the 1980s, the metal forming industry moved toward hybrid systems that use mechanical parts, hydraulic actuators, and synchronous electric motors. This phase led to the development of semi-automatic machines, which use electrical controls and limit switches to control cutting lengths, speed, and some forming actions. The worker is still responsible for setting up rollers and changing wire coils, though[03].

I.5.4 Comprehensive Mechanical Automation

Innovations in twisting and eye creation around the start of the 20th century, as evidenced in the works of Edenburn, made it possible to automate most repetitive machine tasks, including as feeding, weaving, twisting, cutting, and even winding the fence into reels so it could be moved and set up. This change is almost like going from "textile simulation" to "full mechanical automation," where the machine decides exactly what movements to make based on a complicated mechanical design, and the worker's only job is to watch and provide the raw wire.

I.6. Introducing modern control systems and transitioning to semi-automatic

I.6.1 Integration of Synchronous Motors

Thanks to the introduction of synchronous electric motors, it became feasible to precisely control the angular speed of the feed and forming axes. This kept the eye dimensions stable and cut down on network errors. Controlling speed and torque also made it possible to work at higher speeds without affecting the quality of the binding. This led to a big boost in production in semi-automatic machines.

I.6.2 Limit Switches

End-of-stroke switches were added to make sure that particular portions of the machine would stop or travel in the opposite direction when they reached a given point, like the cutting position or the end of the wire roll-forming action. This helped cut down on mistakes people

made when figuring out how long the fence was or how many eyes it had. It also made it possible to repeat the same operational cycle without needing a worker to do it.

I.6.3 The Shift Toward Simple Digital Control

In recent decades, research in metal forming has led to the use of simple digital control, like programmable logic controllers (PLCs) or simple logic systems, to change the timing of motions and the order of forming operations. Because of this level of automation, it was possible to make semi-automatic machines that had pre-programmed dimensions for the eyes, the length of the fence, and the speed of operation. The machine then runs the cycle on its own, with only a little help from workers who monitor and feed it.

I.7. Fully automated machines and computer control Fully automated machines and computer control

I.7.1 Integration of Advanced Programmable Control Systems (CNC/PLC)

Programmable controllers that are very efficient are becoming more and more common in the production of metal fences. These controllers let you change operational parameters using digital interfaces and save different production programs. Using these systems, you may vary the size of the mesh apertures, the type of wire (diameter, substance), and the speed at which the machine works. You can also keep an eye on the machine's condition using sensors that check the tension, motor temperature, and number of cycles.

I.7.2 Integration of Multiple Ax's and Feed Automation

Modern machines include multiple servo axes that can regulate wire feeding, shaping, and cutting at the same time. They also have automatic feeding systems for wire coils that cut down on downtime. Sensor systems can also find broken or abnormal wires early on and automatically stop the operation or fix the problem without needing to be manually intervened.

I.7.3 An example from recent design studies

Studies on the design and manufacturing of metal fence-making machines show that modern systems aim to reduce costs by combining a strong mechanical structure with a flexible control system that uses commercially available parts (motors, sensors, and PLCs) while still making high-quality fences quickly. These studies also look at how easy it is to maintain and use by making simple operational interfaces and units that can be taken apart and put back together fast in small and medium-sized industrial workplaces[03].

I.8. Components of the modern metal fence manufacturing machine

Components of the modern metal fence manufacturing machine

I.8.1 Mechanical Components

- A strong frame that can handle vibrations and forming forces.
- Forming rollers bend the wire at a certain angle and diameter to make the cells.
- A cutting mechanism with knives or cutters that works at the same time as the feeding operation.

These parts are made to be both strong and flexible, and they are made of materials like medium carbon steel or alloy steel that are resistant to wear.

I.8.2 Power and Motion System

- Electric motors that work at the same time or at different times, depending on how far along they are in their development.
- Drive systems (belts, chains, and gears) that send torque to the forming and feed axes.
- Sometimes hydraulic or pneumatic systems are utilized to move the cutting tools or tighten the wire.

The torque, speed, and duty cycle needs of the production line determine which power system to use.

I.8.3 Control and Sensor System

- A digital controller or programmable logic controller (PLC).
- Limit switches that let you change where the cutting and shaping tools are.
- Speed and tension sensors, as well as wire break points, give signals to the controller right away so that it can make the right choice.

This system shows the technical line between semi-automatic and fully automatic machines, as the machine's ability to make decisions on its own grows[04].

I.9. Steps for regular and preventive maintenance of the metal fencing machine

I.9.1 Daily and Weekly Maintenance

- Cleaning the regions where the shaping and cutting happen of wire scraps and other dirt to keep the pulleys and blades from wearing out.
- Check the gears and belts for tightness, and make sure you frequently tune or oil the moving parts.

- Checking the input wires to make sure they are in good shape and don't have any serious problems (like dents or rust) that could cause them to stop working.

These easy steps cut down on unexpected problems and keep the eye measurements in the final output at a high level.

I.9.2 Monthly and Quarterly Maintenance

- Checking the alignment of pulleys and forming pieces with basic measuring equipment and making adjustments if the network dimensions don't match up.

- Adjusting limit switches and making sure that stop and cut points are correct, especially after repairs or part replacements.

- Keeping an eye on the motors' temperature while they are running and comparing it to the load current analysis to look for indicators of overload or friction.

This degree of maintenance helps power and motion parts last longer and cuts down on long periods of downtime during production.

I.9.3 Corrective and Developmental Maintenance

- When wear goes beyond acceptable levels and affects the quality of the product, replacing broken pulleys or cutting knives.

- Updating the control unit or adding new sensors to make operations more efficient and keep an eye on problems, especially on manufacturing lines that are switching from semi-automated to automatic.

- Regularly updating the software on digital control units to make sure they meet safety and quality standards.

This kind of maintenance is part of the strategy for ongoing improvement in medium and big factories[05].

I.10 Conclusion

a general overview of chain-link fence manufacturing technologies has been presented. The different types of fence-making machines, their main components, operating principles, control systems, maintenance procedures, and safety aspects were discussed. This review provides the theoretical foundation necessary for understanding the industrial context of the project and serves as a basis for the theoretical study presented in the next chapter

Chapter II

Theoretical Study of a Wire Mesh Manufacturing Machine

II.1 Theoretical introduction

The manufacturing of woven wire fence belongs to the applicable branches of cold metal forming and wire processing techniques. This industry is based on the transformation of low carbon steel wires into an interconnected mesh structure with a regular diamond pattern providing at the same time the mechanical properties for protection and durability and the optical and air permeability properties needed in a number of fencing applications. This sort of fence is comparatively lighter than other typical fencing options such as concrete walls or full metal panels. Its resistance to environmental elements can also be strengthened with surface treatments such as hot dip galvanizing or plastic coating, giving it a long operating life and making it widely utilized in agricultural, industrial, security and infrastructure projects [06].

The progress of industrial automation systems and electromechanical control has led to significant improvement of the manufacturing technologies of fence networks during the last few decades. The combination of high-precision electric motors, optimized transmission systems and programmable control units has boosted the production speed, improved the regularity of the mesh apertures and decreased the rate of human errors and loss of raw material. In this sense, semi-automatic machines have appeared as a compromise solution both technically and economically, uniting the simplicity and low cost of manual operation with the advantages of automatic control at the necessary stages of the production process, such as feeding the wire, forming regular bends, intertwining wires, the final winding and cutting operations. This makes this kind of machine suited for small and medium-sized firms and resource-limited industrial projects [07].

II.2 The general study of the project

II.2.1 Definition of the industrial problem

To make chain-link fences, metal wires are bent into a constant geometric shape that strikes a compromise between strength and flexibility. This process entails transforming the metal wire into a helical configuration and subsequently interconnecting it with other wires to build a network characterized by consistent openings.

Even though this industry has made a lot of progress, many small and medium-sized workshops still rely on manual or semi-traditional methods, where the worker is responsible for feeding, bending, and weaving. This leads to several technical problems, the most important of which is that the quality of the products is not always the same because of changes in execution accuracy, lower productivity, and higher stress levels at work.

However, current industrial systems rely on complete automation, wherein interconnected mechanical and electrical systems control every aspect of production. This makes production incredibly precise and reliable. However, these systems need a lot of money to set up and run, and they are hard to maintain and operate, which makes them unsuitable for workshops with limited space, particularly those that cannot afford the high initial investment or lack the technical expertise required for operation.

Thus, it is important to set up a middle-level production system based on the idea of semi-automation. This will improve production efficiency while keeping design simple and affordable[07].

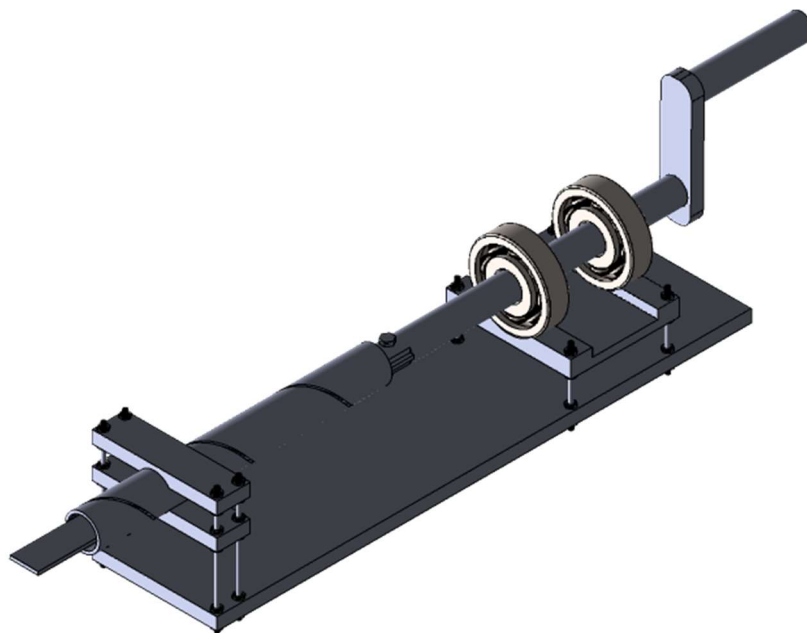


Figure 0-2 Principle of Operation of the Wire Forming Mechanism

II.2.2 Project objectives

This project aims to develop an engineering model for a semi-automatic machine that fabricates metal fences. The machine should be able to balance low cost and ease of use with high production efficiency and technical quality. This goal is based on a number of engineering factors that have to do with improving the weaving process and making the worker less important.

The project also wants to improve the final result by controlling the mesh's basic technical features, like the angle of bending, the diameter of the wire, and the spacing of the holes. This will make sure that the mesh structure is geometrically sound. This is a key step in making the fence stronger, especially when it comes to how much it can stretch and how it can change shape.

The project also wants to lower production costs by using standard mechanical parts and simple manufacturing methods that make it easier to maintain and replace parts. This makes the project more useful in the community.

This program helps the economy and society by making more jobs. A semi-automatic machine doesn't get rid of the need for people to work; it just adds to the process of making things. This machine needs people to watch over it, feed it, and make sure it works properly. It creates jobs and lowers unemployment rates, especially in small and medium-sized businesses. You can also find a balance between automation and human supervision with this kind of system. This makes manufacturing more flexible and makes it easier to meet the needs of the local market.

II.2.3 Methodology

This project used an analytical-design method, which meant dividing the work into smaller, related parts. The first step was to figure out what the industrial problem was and what the performance standards were. The second step was to come up with a conceptual design, which meant figuring out how the machine would work and how all the parts would fit together.

The next step is to make a full design. This means modeling a few mechanical parts, figuring out how big they need to be, and doing some basic engineering calculations to figure out how much power, torque, and force they need. At this point, the parts that would move and the bearings were chosen based on how well they would work.

Then, computer-aided design tools like SolidWorks were used to make a 3D model of the machine.

II.2.4 The required technical specifications for the machine

The machine's technical specifications depend on the physical and engineering aspects of the metal fence manufacturing process. For example, the machine must be able to feed wire continuously and evenly, and it must be straight before the forming stage to avoid engineering flaws in the final product.

The machine must have a precise bending mechanism that can bend the wire to a certain radius while keeping the twist angle the same. This directly affects how regular the mesh holes are. Also, the weaving mechanism needs to make sure that the wires are always interlaced without slipping or bending.

From an energy point of view, the machine needs to run at the right power level, which is a balance between performance and consumption. It also needs to use a transmission system that cuts down on mechanical losses. To make sure that the basic parts can handle repeated loads, they must be made of materials that are very strong, like carbon steel or alloy steel. The machine must follow safety rules for the workplace by limiting exposure to moving parts, using the right mechanical protections, and making sure it is easy to use and maintain[07].

II.3 Definition of basic concepts

The definition of basic ideas is a vital methodological stage in engineering research, because it helps to unify the technical terminology and clarify the scientific framework on which the research is based. It also helps to develop a logical progression from the theoretical to the practical aspects of the project. In this framework, we find a collection of basic concepts:

II.3.1 The woven metal fence

It is characterized as a mesh of low carbon steel wires in an interwoven helical pattern that creates evenly diamond-shaped holes. The connecting of wires in this construction, besides optical and air permeability, gives the fence key mechanical features such as stiffness, tensile strength and impact resistance. The functional properties of the fence are determined by technical variables, the most important of which are the diameter of the wire used, and its influence on durability, the size of the mesh openings related to the level of security and the type of surface treatment for improved corrosion resistance [07].

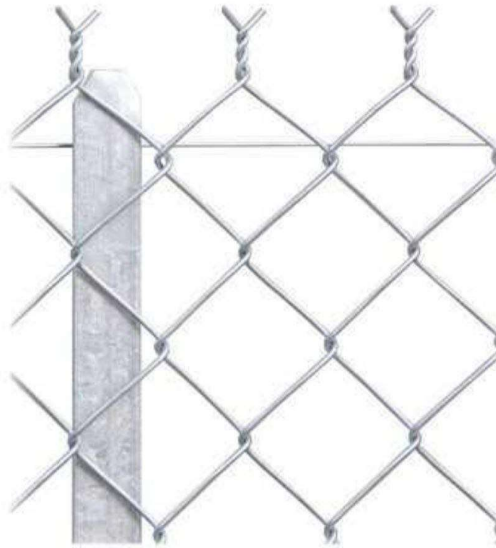


Figure 0-3 The woven metal fence

II.3.2 The metal wire

Wire is basically a flexible thread of metal. It is formed by the "drawing" process. The drawing process involves pulling the metal through an opening in a mould called a "drawing die" which reduces its diameter, but increases its length. The wire is circular in cross-section (but may be square or rectangular in rare instances) and has certain mechanical properties like as durability and bendability. Low carbon steel is typically used for the wire, which is very durable in the context of making the metal fences. It is chemically treated in a process called "galvanization", where it is covered in a layer of zinc to prevent it from oxidization and harsh weather conditions. It is a crucial, sturdy component of the mechanical weaving process [07].



Figure 0-4 The metal wire

II.3.3 The mechanical weaving of metal wires

It is a continuous manufacturing process in which a straight metal wire is transformed into an interconnected mesh structure by a series of regular bending and repeated entanglement operations performed with the help of a moving mechanical system. The method is based on the principles of mechanics of metal plastic formation, when the wire is under bending stresses within the limits of the change of shape without destruction. The basic procedures include feeding the wire, bending it at the required angles, interlocking successive wires and coiling or cutting the mesh. The feeding speed and the bending and interlocking movements must be very well timed so as not to distort the product [08].

II.3.4 The semi-automatic machine in manufacturing

It is an electromechanical manufacturing system with partially automated control of fundamental processes with limited human participation in monitoring, adjustment and feeding. It is an engineering solution for the average between the manual machines and the fully automatic machines characterized by simple design, low energy consumption, easy maintenance and that can be handled by a single worker with industrially acceptable productivity [08].

II.4 The importance of theoretical study

Theoretical study is the basic pillar on which any successful engineering project is based. It ensures a deep scientific understanding of the physical and mechanical phenomena related to

the operation of the industrial system before going to the stage of design and practical implementation. Its relevance branches out in the following points:

II.4.1 Building comprehensive scientific understanding

It gives a framework which explains the behavior of the wire during bending and tangling and the linkages between stresses and plastic deformations. It can be used to analyze motion transfer and the effect of speed and torque on process stability, avoiding random experimentation [08].

II.4.2 Support design and reduce errors

It helps in determination of right size and choice of suitable materials for load bearing capacity. It also aids in the calculation of the power needed for the engine, planning of transmission systems and safety aspects, reducing chances of failures and balanced design [09].

II.4.3 Improving efficiency and reducing costs

This comprises finding out the best weaving speed for the highest production without impacting the network quality and contrasting possibilities to pick the most profitable solution depending on the number of parts, energy consumption and running expenses [10].

II.4.4 Product quality assurance and development potential

The theoretical basis allows managing the parameters influencing the quality, such as the regularity of the apertures and the strength of the bonding. It also allows future machine growth by adding digital control systems or smart sensors [11].

II.5 Control theory, automation, and motion systems

Control and automation theory represents the mathematical and engineering foundation for regulating the behavior of industrial systems and ensuring a precise and stable response despite external disturbances or changes in operating conditions.

II.5.1 Motion systems

The fence weaving machine relies on the integration of three main systems: the mechanical system (converting rotational motion to form the mesh), the electrical system (providing power and kinetic energy), and the control system (controlling speed, aperture dimensions, and cutting timing) [12].

II.5.2 Dynamic control

The control system seeks to allow the perfect synchronization of the motions of the machine in order to obtain a grid of equal dimensions. In closed loop control, the output is measured and compared with the reference value and adjusted to reduce the error for operational

precision. One of the most extensively utilized are the PID controllers, which provide tissue speed stabilization and vibration reduction by balancing reaction speed and control accuracy [12].

II.5.3 Industrial control systems

The control system is designed to ensure precise synchronization between the machine movements in order to produce a mesh with uniform dimensions. A closed-loop control system is used to maintain operational accuracy by measuring the output, comparing it with the reference value, and adjusting the control signal to minimize errors. The PID controller is widely used because it provides a good balance between fast response and control accuracy, helping to stabilize the weaving speed and reduce vibrations [13].

II.6 Dynamic analysis and vibrations

Dynamic and vibrational analysis is the backbone to ensure the sustainability and precision of high-speed industrial machines. In wire weaving machines, the mechanical parts transition from a state of rest to high rotational and linear speeds in fractions of a second, generating enormous inertial forces that directly affect the stability of the structure and the quality of the final product.

II.6.1 multi-axis system analysis

The analysis is based on varying moments of inertia of the feed rollers with wire consumption, which demands a careful investigation of the mass distribution. It also studies forces interaction between shafts, where the acceleration generates a reaction torque propagating through the structure, as well as analyzing the transient loads and shocks that arise from the entanglement or rupture of wires to avoid the phenomenon of mechanical fatigue [14].

II.6.2 Dynamic stability

Random mechanical vibration is seen as a barrier to manufacturing accuracy. The machine is represented with a given number of degrees of freedom and each part is connected with mass, stiffness and damping coefficient. The engineering aim is to avoid the natural frequencies of the system so as to prevent the resonance phenomenon that might lead to a detrimental amplification of the vibration amplitude. Static damping methods (e.g. vibration-absorbing materials such as rubber) and active damping (control systems producing counter motions) are utilized [14].

II.6.3 Mathematical modeling of vibrations

The system is represented by a mass-spring-damper model, which is used to evaluate stability by studying the time response and ensuring that vibrations caused by shocks dissipate as quickly as possible [14].

II.7 Power and energy calculations

The weaving process in wire mesh machines relies on overcoming the metal's resistance to deformation.

II.7.1 Formation strength calculations

In order to obtain persistent entanglement, the applied force must be greater than the yield point of the metal and enter into the plastic deformation zone. The needed bending moment depends on the wire diameter and material qualities, and the larger the diameter the larger the forces need to be. The analysis comprises the study of the torsional moment necessary to twist the wire. The bending stress is converted into shear stresses, which require the twisting heads to possess high strength [15].

II.7.2 Energy consumption

The mechanical power is the sum of the torques needed for the form and the torques of friction in the bearings and gears and the torque of inertia for the acceleration of the parts. These forces are transformed into electrical power demands on the motor, assuming losses in the gearbox to keep operational efficiency viable [15].

II.8 Mechanical structure design

This section focuses on building a physical entity capable of withstanding the combined stresses resulting from the continuous weaving process.

II.8.1 Stress analysis

The machine's parts are subjected to combined loads (tension, compression and torsion). We utilize the equivalent stress principles to evaluate the capability of the material to suffer plastic deformations, focusing on the stress concentration locations at the corners and holes and including a safety factor to ensure the machine works under overload conditions [16].

II.8.2 Selection of materials and treatments

The bases are made of structural steel in order to absorb vibrations and the columns and gears are made of heat-treated steel alloys for resistance to wear and mechanical fatigue. Then they harden the surface of the forming sections to increase their hardness, keeping the core metal flexible enough to absorb shocks [16].

II.9 Quality and safety standards

This section relies on two parallel concepts: reliability management (to ensure quality) and risk engineering (to ensure safety), and transforming them into practical standards.

II.9.1 Quality standards and control

The product must conform to international standards (e.g. ASTM A116) for the precision of the hole measurements and the integrity of galvanization. High torque forces might shatter the zinc coating, leading to rust. The control system also has statistical quality ideas, with sensors that statistically evaluate the process capabilities to keep production within limitations [17].

II.9.2 Engineering and safety standards

Safety is seen as a necessary condition under rigorous restrictions. Stop circuits are designed for maximum safety integrity and dependability employing redundant designs to prevent the failure of any component. The risk control pyramid is applied by means of engineering removal, interlocking physical barriers and photoelectric curtains. The design targets comfortable safety to minimize the muscle strain for the operator and avoid work-related injuries [18].

II.10 Industrial standards (Les Norms) and ISO standards

II.10.1 The concept of industrial standards and their importance

Industrial standards or “Les Norms” are regulations and technical specifications issued worldwide or nationally to standardize work processes in the sectors of design, manufacturing and testing. Such standards are viewed as the foundation of the modern industry. Their aim is not only to provide the quality of products but also to safeguard the safety of workers, make maintenance operations easier, and decrease the possibility of malfunction. It is also essential in ensuring the interoperability of diverse systems and in boosting the competitiveness of products in global marketplaces. These standards are published by major global organizations such as the International Organization for Standardization (ISO), the American Society for Testing and Materials (ASTM) and the International Electrotechnical Commission (IEC) as well as organizations such as DIN, EN and ANSI [19].

II.10.2 The nature of the ISO organization and its standardization role

ISO (**I**nternational **O**rganization for **S**tandardization) is the world’s leading reference for developing standards that cover a wide range of engineering, industrial and administrative sectors. The major strength of ISO standards is the capacity to standardize technical

specifications across geographical boundaries thereby strengthening the reliability of the system and the overall quality of the industry. Organizations implementing these standards can boost workplace safety, support international trade and attain increased efficiency in managing complex industrial operations [20].

II.10.3 The standards applied in the project and their technical applications

The preventative element and the qualitative one of the projects are founded on some major standards, the first of which is the **ISO 12100** on safety of machinery. This standard specifies the methods for risk analysis and the safe operating interface design. The project demonstrates this by installing protective covers and emergency stop devices. At the same time, **ISO 13849** is used to assure the reliability of control system components, which ensures the safe operation of sensors and stop circuits in cases of failure of the electric. The **ISO 9001** standard is a key quality management tool used to regulate dimensions and differences in the final product by monitoring operations and documenting production phases [19].

In terms of physical protection, **ISO 14120** specifies the requirements for the design of protective barriers to prevent operator access to rotating parts or dangerous cutting areas.

ISO 13850 specifies the requirements for the emergency stop function, including the speed of response, the location and the color of the button, to ensure immediate intervention in the event of any danger [19].

II.10.4 Material quality standards (ASTM A116)

The **ASTM A116** standard is used to assure the durability of the end product (metal fence), to specify the mechanical and physical properties of steel wires. This standard provides a clear description of standards for tensile strength, quality of galvanizing procedures and thickness of the zinc coating required to preserve the wire from corrosion and environmental conditions therefore giving a long potential lifetime for the produced metal mesh [20] [21].

II.10.5 The overall impact of applying the standards on the project

The observance of this set of industrial standards is not only meant to achieve technical quality, but also directly helps to boosting the reliability of the machine and decreasing the costs of unexpected breakdowns. It also ensures a fully safe working environment for the operators and makes the final product comply with international criteria, enabling future maintenance operations and improving the economic and competitive worth of the project in the industrial market [22].

II.11 Worker safety measures and prevention of occupational hazards

The safety of the operator is of primary concern in the design and operation of industrial machines. The safety is not only physical barriers to the machines but also to provide a work environment that avoids injuries due to human errors or sudden mechanical failures. This is done by installing photoelectric sensor systems that will quickly stop the machine when a worker's hand comes close to the danger zones. Clear warning labels are also posted describing safe operating methods and electrical isolation locations. Design also has the aspect of applying “ergonomics” to provide a pleasant working position that decreases the physical strain on the worker and eliminates mishaps due to exhaustion or lack of concentration [23].

In addition, specific standards are implemented regarding personal protective equipment (PPE) must be worn when working the machine such as cut-resistant gloves and safety eyewear to protect against possible metal shavings during the wire weaving process. This also involves training the worker on “lockout/tagout” procedures during periodic maintenance operations to prevent the machine from being mistakenly started up while the technician is inside it. Safe mechanical design combined with continual human training results in the lowest rate of occupational injuries and stable operation of manufacturing facilities.

II.12 Conclusion

This chapter presented the theoretical background required for the design of a semi-automatic fence manufacturing machine. The study covered the manufacturing process of wire mesh, the fundamental engineering concepts, control systems, power transmission, vibration analysis, quality standards, and safety requirements. These theoretical elements constitute the scientific basis for the design and development of the proposed machine described in the following chapter.

Chapter III

Components and Conception of Fence

Making Machine

III.1 Introduction

The machine that makes metal fences takes a continuous rotational motion and turns it into a succession of mechanical tasks, such feeding, shaping (helical bending), weaving, and drawing.

The wire is drawn from the spool while it is under a continuous tension strain. This makes it straight again, so any bends that occurred while it was being stored are gone. Then, the wire proceeds to the shaping device, where it is twisted along a specified axis. This causes the wire to bend into a helical form with a radius that stays the same.

The bending process can be connected to the interaction between:

$$T \geq \sigma_y \cdot Z \quad (0-1)$$

(Where σ_y is the yield stress and Z is the section modulus).

After being shaped, the helical wire is put into a preceding wire by moving it along its length, which causes the wires to interlock in a periodic geometric pattern. This procedure doesn't use welding; instead, it uses mechanical interlocking, which makes the mesh very flexible.

III.2 The career plan

The functional diagram is an analytical engineering tool that breaks down the mechanical system into a sequence of logical processes that happen one after the other. This study looks at how matter, energy, and information move through the machine. It helps us comprehend how the mechanical and electrical parts work together without getting into the minutiae of how the machine is built right now[24].

III.2.1 Analysis of Input System:

There are three main types of inputs that work together to keep the machine going:

Raw Material: It is made of coils of metal wire. The material is tested for its mechanical properties, such as "Yield Stress," which shows how much energy is needed to shape it, and "Nominal Diameter," which refers to the size of the mechanical parts that touch the wire.

Energy Input: The induction motor must change electrical energy into kinetic mechanical energy for the system to work. This study investigates energy transfer concerning "mechanical efficiency" and the energy dissipation caused by friction in gears and pulleys.

Control and Information: In the semi-automated system, the operator is the feedback loop. They change the speed settings and step in to correct the course. This makes the system a "hybrid system" that uses both machine accuracy and human judgment.

III.2.2 Processing Units Processing Units:

Processing happens through several functional units that are coupled to each other:

Feeding and Straightening Unit: This is the part that gets the material ready. From an engineering perspective, this unit gets rid of the wire's "mechanical memory" that comes from circular storage. This makes sure that the wire enters the forming region in a perfectly linear state, which is necessary for the mesh to be regular.

The Forming & Weaving Unit: is the most important part of the process. It changes rotational motion into helical motion. This unit uses just mechanical interlocking, so there is no need for welding. This keeps the chemical qualities of the galvanization layer intact and protects it from heat corrosion.

Pulling and Finishing Unit: It controls how fast the finished product leaves the machine, which is the same pace as the weaving. If the wires get out of sync, they may stretch or build up, altering the hole shape.

III.2.3 System Outputs and Losses:

The system output has two parts:

- **The main product:** is a wire fence with basic features like regular openings and great durability.
- **Secondary outputs (System Losses):** This is the energy that is lost as heat because of noise, mechanical vibrations, and the wire rubbing against the mold. Studying these secondary outputs in theory can help make machine bases better and pick the right lubricants to save energy.

III.3 Geometric analysis for system selection

When we designed and built the machine that creates metal fences, we didn't just pick to employ a semi-automatic method at random. Engineers did a lot of research and then choose between three primary methods to run: the manual system, the semi-automatic system, and the completely automatic system. There were both technical and financial grounds for making this option. The objective was to identify a compromise between performance, cost, and reliability, all in the sake of keeping the business running.

III.3.1 Evaluating Cost-Effectiveness:

The semi-automated system is a suitable choice from an investment point of view since it finds a fair balance between cost and performance. Fully automated systems need programmable logic controllers (PLCs), modern sensors, and control software, which makes the project more expensive.

It costs a lot of money in labor to do things by hand, and it doesn't get done very quickly

III.3.2 Productivity efficiency and quality assurance:

In industrial engineering, process stability is a major indicator of how well something is performing. The manual approach is affected a lot by human variables like weariness and mistakes, which changes the quality of the final result.

The semi-automatic system is built on the premise that machines may repeat themselves. This implies that it employs a motor and a fixed shaping mechanism to manufacture metal fences with holes that are always the same size and shape. This technology also speeds up manufacturing compared to doing it by hand while still maintaining excellent quality and satisfying market demands.

III.3.3 Simple and reliable technology Reliability and ease of use:

Lean Design is what makes the semi-automated system work. This is because it doesn't have the problems that come with fully automated systems, including having too many sensors and complicated programming.

This simplification makes technical problems (System Failure) less likely, which makes the system more reliable.

The clear design of the mechanical and electrical systems also makes it easier to identify and diagnose problems, which improves efficiency.

a) Engineering for maintenance and logistics

When assessing industrial systems, maintenance ease is crucial. The semi-automatic system is simple to fix on-site because it doesn't require extensive programming expertise or complicated electrical parts.

This means :

- Less down time
- Cutting down on maintenance expenses
- Keeping things running smoothly in small and medium-sized industrial settings

b) The model for optimization:

A mathematical model that shows how efficiency, cost, and complexity are related may be used to show how to choose the best system:

$$\text{Efficiency} = \frac{\text{Quality} \times \text{Productivity}}{\text{Cost} \times \text{Complexity}} \quad (0-2)$$

• **Quality:** Quality of the final product

• **Productivity:** Production rate

- **Cost:** Total cost (investment + operation)
- **Complexity:** Degree of system complexity

This model shows that the semi-automatic system strikes the optimal balance since it combines the following:

- The quality of this semi-automatic system is nearly as high as that of fully automated systems.
- Not as expensive as it.
- It is easy to use and maintain compared to both manual and automated methods.

III.4 Looking into the Human-Machine Interaction System

When working on engineering projects that involve manufacturing, choosing how much automation to use is a strategic decision that depends on finding the right balance between quality and cost. The machine that makes metal fences is a "hybrid system," which means that the mechanical parts of the machine and the worker's brain work together to do tasks. The goal is to have a lot of flexibility in production and stable operational efficiency[25].

III.4.1 How to divide up work assignments:

The system works best when tasks are divided in a way that takes into account the strengths of both the computer and the person doing the work:

- **What the machine domain does:** The machine is responsible for doing tasks that need a lot of mechanical power and need to be done over and over again (high repetitive tasks). For example, the bending process needs a constant torque, the weaving process needs geometric precision in the path, and the pulling process needs a steady speed to keep the formation stable.
- **The human worker's job (human domain)** is to do activities that need cognitive flexibility and the capacity to make decisions. For example, they feed wires, inspect the visual quality, and manage when the manufacturing process starts and stops based on how the system is doing.

III.4.2 The scientific mathematical basis (optimization problem):

Choosing a semi-automatic system may be thought of as an optimization issue that seeks to find the optimal balance between cost, productivity, and complexity. This can be seen by the general relationship:

$$f(x, y) \rightarrow \textit{Optimal Balance} \quad (0-3)$$

We can examine the three systems in the following ways, where the variables represent the system's features (productivity, cost, complexity):

- **The manual system:** It has a low starting cost, but it has low productivity and quality that isn't always steady because it relies completely on people to do the work.
- **The completely automated system:** is the most productive and accurate, but it costs a lot of money to set up and keep running, and it is quite complicated to build and maintain.
- **The semi-automatic system:** (the one we picked) is the best choice since it boosts productivity a lot compared to the manual system while keeping the design simple and the cost cheaper than fully automated systems.

III.5 Finding out how big the mesh should be

The dimensions of the metal mesh are a set of engineering parameters that determine the shape and size of the openings in the metal fence. The helical wires that fit together create these openings. These measurements have a big effect on how well the finished product works and how strong it is, such as its tensile strength, weight per square meter, and visibility[26].

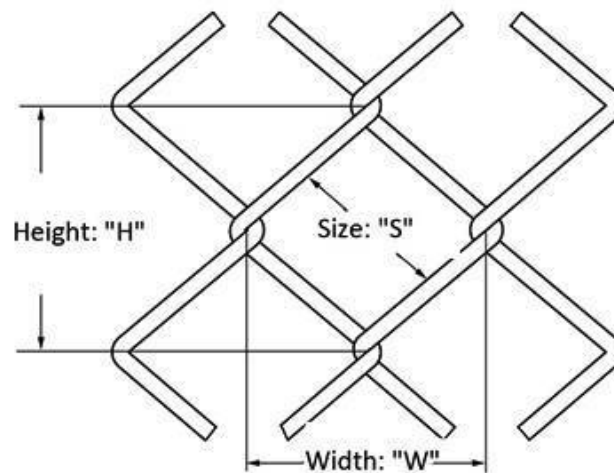


Figure 0-5 The basic geometric dimensions of the metal fence network

III.5.1 Analytical engineering for the fence's opening the analytical geometry of the opening in the fence:

The hole in the fence looks like a diamond. To understand how this design is made, you need to follow the wire as it spirals around the mold that is being made. A rhombus has two sides that are the same length and two diagonals that are at right angles to each other. The size depends on the following information:

- a) **The side of the rhombus (S):**

The length of the wire makes up one side of the diamond-shaped hole. In theory, the length of this side depends on the diameter of the forming die D (Mandrel) and the angle at which the wire is wound. When something bends, S is the hypotenuse of a right triangle that forms.

b) Formation angle (θ):

The angle between the wire's direction and the mold's axis of rotation is what it is. The angle has a direct effect on how long the diamond shape gets; if the angle is

$$\theta \approx 90^\circ \quad (0-4)$$

III.5.2 Criteria for establishing measures

The network dimensions are established according to functional requirements, conforming to international standards (e.g., ISO or ASTM). These dimensions are regulated mechanically through:

a) Modifying the auger mold: to alter the diameter of the aperture a

b) Adjusting the pitch (Pitch p): to ensure the wires interlock evenly without excess gaps or jamming.

III.5.3 The basic design variables

The quality of the woven fence is determined by the adjustment of four interconnected variables:

Wire diameter (d): It determines the mechanical resistance, and the force required for shaping is directly proportional to d^3 .

Mesh opening (a): It represents the net distance of the diamond, which determines the material consumption and the overall weight.

Twist angle (θ): It usually ranges between 60° and 90° ; where a sharp angle affects wire consumption and longitudinal tensile strength.

Bend radius (R): It must meet the engineering standard ($R \geq 2d$) to avoid micro-cracks in the galvanizing layer.

$$a \approx 2 \cdot R \cdot \cos \left(\frac{\theta}{2} \right) \quad (0-5)$$

Rule of Thumb for Industry: When circumstances are normal ($\theta \approx 90^\circ$), the mesh opening (a) is about the same size as the mold's outer diameter (d). This is because of the balance of physical effects (wire thickness + elastic rebound + clearance).

III.5.4 Geometric equilibrium analysis

The appropriate design relies on a three-way balance that ensures the stability of the machine system:

Durability: As d gets bigger, it gets stiffer, but the engine needs more torque to do this.
Economy: Making the aperture (a) bigger makes it lighter and cheaper, but it makes it less safe.
Precision: The weaving angle (θ) stays the same, which keeps the geometric form regular and eliminates jamming.

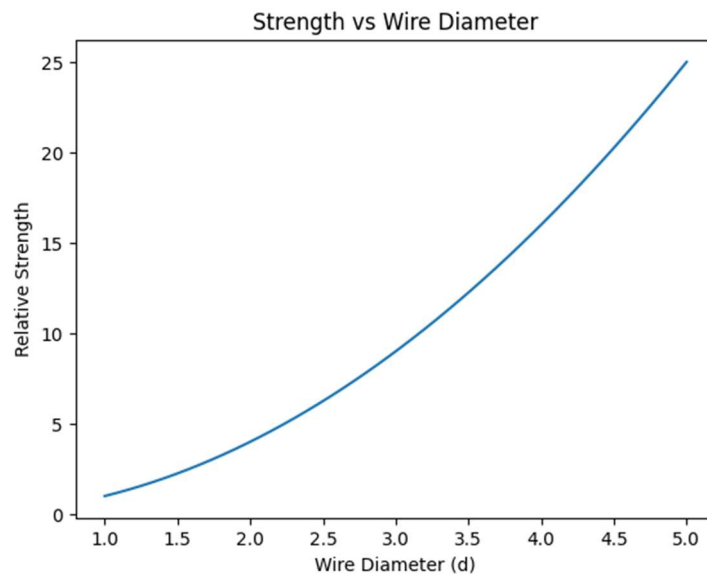


Figure 06- Strength vs Wire Diameter (d) [1]

The larger the diameter of the wire $d \rightarrow$ the resistance increases significantly.
This proves that a slight increase in diameter provides significant rigidity.

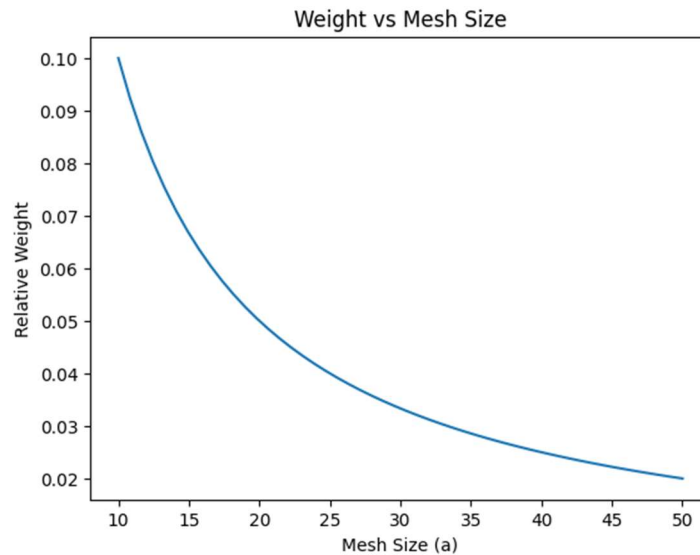


Figure 0-7 Weight vs Mesh Size (a) [2]

The larger the mesh opening $a \rightarrow$ the lower the weight

Large openings cost less but provide less safety.

From the curves, we can see that making the wire thicker makes it much more durable, but making the mesh hole bigger makes it lighter and cheaper. So, picking the best values depends on finding a compromise between these two aspects without lowering the quality of the engineering.

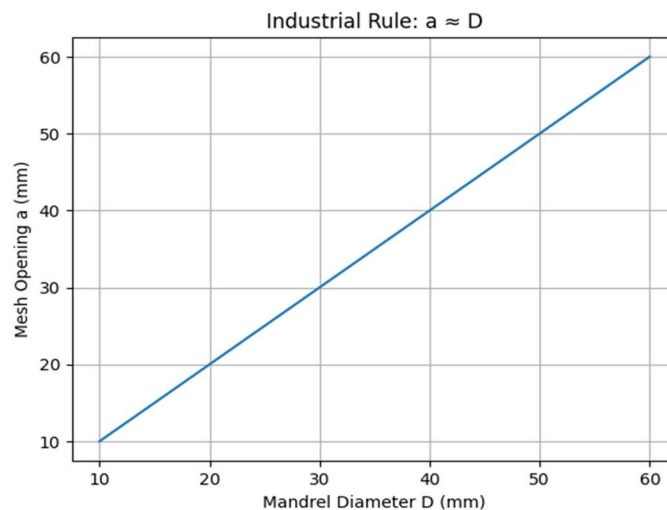


Figure 0-8 The relationship between the mesh opening and the mold diameter [3]

The size of the metal mesh depends on the size of the mold used in the forming process. In industrial settings, there is an almost linear connection between the two, ($a \approx D$), which is in keeping with the rules of metal forming.

III.6 Mechanical design

III.6.1 General definition of the mechanical structure

The machine's mechanical structure (chassis) is the fundamental frame that supports all of the machine's mechanical and electrical pieces. It is also the bearing element that keeps the different parts in the right place when the machine is running. This part is the most important part of the machine's design since it gives it the strength it needs to hold up under static loads (like the weight of the parts) and dynamic stresses (like movement and rotation).

The structure also helps keep the many parts of the system, such as the guide rail, mold, and feeding system, in the right geometric alignment. This step is important for making sure that the forming process is accurate and that the end product is of high quality. It also helps reduce vibrations caused by the motor's functioning and the transfer of motion, which makes the machine more stable and lasts longer.

The chassis holds the pieces together and keeps them from slipping or moving in ways that may put users at risk. The mechanical structure is a key part that combines stiffness, accuracy, and stability. It is necessary for the machine to work as well as it should.

III.6.2 Analysis of loads and stresses affecting the structure

While the machine is running, it has to deal with a number of mechanical loads that affect its stability and overall performance. There are two kinds of these loads: static loads and dynamic loads. Static loads are the weight of the structure itself and the weight of the parts that are attached to it, such as the electric motor, speed reducer, forming system, and pulleys. These are loads that stay on the base and hold it up all the time.

The dynamic loads come from the motor turning, the parts of the system moving, and the forces that come up when the wire bends while it is moving through the mold. These loads change over time, and if they aren't taken into account when designing the machine, they can cause vibrations that make the machine less accurate.

The structure is under a lot of stress from a mechanical point of view. Bending stress from loads on the horizontal parts, shear stress from fastening forces, and compressive stress on the vertical and slanted supports are the three most important types of stress. These stresses need to be lower than the material's resistance limits to avoid permanent deformation or mechanical failure.

The way loads are spread out is also very important for how the structure works. It is built so that forces are evenly spread out, which keeps stress from building up in certain areas. This could make those areas weak or cause them to break. This is why more braces are put in sensitive areas to make them stronger and less likely to bend.

Therefore, it's very important to look at all the loads and stresses when designing a building. This is because it makes the machine more reliable and efficient by making sure that the structure is strong and long-lasting while still being light and cheap[27].

III.7 Choosing materials

III.7.1 Electric Motor

Choosing the right materials is one of the most important steps in building the machine's mechanical structure since it has a direct effect on how well it works, how long it lasts, and how long it may be used. Engineers and economists choose materials depending on a number of factors, including how well they can handle stress, how hard they are, how well they resist wear, how easy they are to make, and how much they cost.

The electric motor is the most important part of an industrial system that changes electrical energy into mechanical energy. A three-phase induction motor is utilized in this project since it is easy to construct, very reliable, and doesn't need much maintenance.

The way this sort of motor works is by passing a three-phase current through the stator, which creates a rotating magnetic field. This process, in turn, creates currents in the rotor, which creates an electromagnetic force that makes the shaft turn. The motor's speed of rotation is near to the synchronous speed, which may be found using the following equation:

$$N_s = \frac{120 \cdot f}{P} \quad (0-6)$$

- N_s : Synchronous speed (rpm)
- f : frequency (Hz)
- P : Number of poles

The induction motor is efficient and can run all the time, so it is used in factories to shape things. It can also work in tough conditions and is often used with safety systems like thermal relays to keep overloads from causing problems. This helps ensure that the motor will last a long time and work reliably in tough industrial settings[28].



Figure 0-9 Electric Motor [4]

III.7.2 Gearbox / Speed Reducer

The speed reducer is a mechanical part that works with the electric motor. It changes the motion characteristics that come from the motor to fit the needs of the industrial application. The electric motor operates at a very high speed, but the bending and weaving operations require a low speed and high torque.

The speed reducer works by employing a collection of gears that are organized in a way that lets them lower the rotational speed and raise the torque. The equation that illustrates the reduction ratio is as follows:

$$i = \frac{N_{in}}{N_{out}} \quad (0-7)$$

- i : Reduction ratio
- N_{in} : Inlet speed (engine speed)
- N_{out} : Exit speed

Thus, the output torque increases according to the approximate relationship:

$$T_{out} = T_{in} \times i \quad (0-8)$$

The speed reducer is very important for making the machine work better since it provides the motor enough torque to create wires, lowers the burden on the motor, extends its life, and makes the movement more accurate and stable.



Figure 0-10 Gearbox [4]

III.7.3 Cooling liquid pump

The coolant pump is the most important part of the fence-making equipment that keeps the process going. The wire inside the mold twists into a helix, which makes a lot of heat because the sliding friction is so high. An effective hydraulic system is needed to keep this heat under control and keep the mechanical parts from getting too hot [29].

The cooling pump is very important for the following:

- Lowering the temperature rise when in use
- Keeping tools from rusting
- Making the end result better
- Making the machine last longer
- Making sure that work goes on without interruption



Figure 0-11 Cooling liquid pump [4]

III.7.4 The helical mold for wire shaping

The helical mold for wire formation is one of the most important parts of the machine that makes metal fences. It changes the shape of the metal wire from straight to helical, which is the shape that makes up the structural base of the metal mesh. The idea behind this technology is forced mechanical forming, which means that the wire is forced to follow a certain path inside a guiding die, which changes its shape forever.

The mandrel and the helical die are the two main parts of this system that work well together. The mandrel is the geometric reference that determines the screw's basic size, such as its diameter and the shape of the holes it makes. As the wire passes through the helical die, it must follow a guiding channel. This keeps the winding process consistent and the final shape the same.

The idea behind this method's forming process is plastic deformation. This means that the wire is bent past the point where it can break, which lets it keep its helical shape after it leaves the mold. There is no need to heat the material because this process is done in the cold state (cold forming). This keeps its mechanical properties and makes sure the sizes are right. The diameter of the ruler, the angle of the helix, the diameter of the wire, and the friction coefficient between the wire and the mold surface are all important geometric factors that affect how the mold is made. It is important to choose these features carefully so that the final product is strong and easy to shape, and the chances of it breaking or deforming unevenly are low.

The mold is made of hardened steel that is very strong and can handle wear and tear because the wire goes through it all the time. (AISI H13) You can also use lubrication methods to reduce friction and make the mold last longer.

The helical mold is a very important part of the manufacturing process because it has a direct effect on the accuracy of the dimensions, the consistency of the shape, and the quality of the metal grid. This is one of the most important things that affects how well and quickly the machine works.

a) Working Principles

The mold works by using plastic deformation, which means that the wire has to bend as it goes through a helical channel.

The procedure runs via these steps:

- The cable goes right into the feeding system. The line comes straight from the system that supplies power.
- It goes into the mold that is shaped like a helix. It goes into the spiral mold.
- The wire is made to follow the mold's helical route. The wire has to follow the mold's helical route.
- The wire goes around the ruler. The wire goes around the ruler.
- The wire comes out in a spiral shape. The wire comes out in a spiral shape.

b) Mechanical analysis of the helical mold

The wire bends as it goes through the helical mold because it has to go around the guide in a curved way. This makes the wire bend in a way that lets it keep its helical shape after it leaves the mold. The torque that is applied must be greater than the material's resistance in order to shape it. This means that it must be greater than the yield stress.

Friction between the wire and mold walls makes movement harder and uses more energy. Therefore, it's better to lower them by using lubricant and making the mold surface smoother. Furthermore, bending the wire at a smaller radius puts more stress on it, which could cause it to break if the right specifications aren't followed.

The mold is stressed and worn from constant contact with other objects. Because of these factors, it needs to be made of lasting materials like hardened steel[30].



Figure 0-12 The helical mold [4]

III.7.5 The ruler

The mandrel or shaping die is the machine's mechanical heart. It changes the spinning kinetic energy of the wire into a consistent geometric shape. The mandrel does more than just serve as a reference point; it is the main factor that determines the mesh's shape and strength, whether that means the size of the holes or the quality of the final interlocking.

a) Geometric analysis and the mechanical role:

The ruler is responsible for determining the fence's standards, as its width and thickness dictate the size of the mesh. In theory, the shaping process has a direct relationship: the bigger the ruler, the bigger the mesh size.

You may figure out the exact **radius of curvature R** that the wire is under by using the following formula:

$$R \approx \frac{D_m + d}{2} \quad (0-9)$$

- D_m : Width or diameter of the ruler
- d : Wire diameter

When you get the rod's diameter smaller, the stress concentration at the bending points goes greater. This might cause the ultimate tensile strength to be reached, especially in wires containing a lot of carbon.

b) Material properties and surface treatment:

The material choice must meet high mechanical standards since the ruler constantly rubs against the metal wire. To make the ruler very hard, which can be more than 55 HRC, it is commonly made of heat-treated alloy steel, such as D2 or H13 tool steel.



Figure 0-13 The ruler [4]

III.7.6 Wire feeding and guiding system

The wire feed rollers move the raw material from the spool that is not moving to the mold that is moving and shaping. These rollers not only move things, but they also fix the wire's original technical problems, like differences in diameter or surface flaws, to make sure the final product is of high quality.

a) Mechanical analysis of the principle of operation

The feeding process uses "rolling contact under pressure," which means that the rollers push down on the wire's surface with vertical forces (normal forces) to create enough friction to overcome the draw resistance and the wire spool's inertia. The roller distance is set to be just slightly less than the wire's diameter. This keeps the wire in touch without changing its shape, which keeps the galvanizing coating's mechanical properties and integrity [31].



Figure 0-14 Wire feeding and guiding system [4]

III.7.7 Manual Cable Cutte

The manual cable cutter is one of the most important instruments for making a metal fence, as it cuts metal wires accurately and easily before putting them into the helical forming system. It uses the idea of the mechanical lever to provide a lot of cutting force while making it easier for the worker to do their job. It is also used during testing and maintenance to rapidly and safely change or remove broken wire sections. This tool helps make better cuts and keeps the wire's form without changing it, which directly affects the quality of the metal mesh that is made. It also makes it easier to do manual labor and cuts down on wasted raw materials while in use [32].



Figure 0-15 Manual Cable Cutte [4]

III.7.8-foot pedal

The foot pedal is an important feature of the machine that makes metal fences because it enables the worker to start and stop the operation with their foot instead of their hands. This makes it easier for the worker to maneuver and manage the equipment while they work. The foot pedal's major job is to start the machine, either by putting wire into it or by turning on the cutting or shaping mechanism, depending on how the machine is made. It also allows you to manage the production process straight away and with excellent accuracy, which makes the end product better. This pedal makes the workplace safer since it allows the machine to stop immediately if there is a problem or a prospective threat. It also implies less work with your hands, which makes you more productive and makes fewer mistakes. It is also said to be a helpful tool that helps people who have to provide the same instructions over and over again feel less tired. Pedals are very important for the metal fence machine to run both the forming and feeding stages at the same time and with excellent accuracy. It also helps with planning production and getting things done faster without sacrificing quality, which is important for keeping the manufacturing process of fence machines running smoothly. This pedal is a key element of semi-automatic systems. This is a section of the fencing machine that blends human control with precise mechanics [33].



Figure 0-16 foot pedal [4]

III.8 Electrical design and control system

III.8.1 The electrical diagram of the machine

The machine's electrical diagram is one of the most important parts of the industrial system's design. The diagram illustrates the flow of electricity through various machine components and its distribution. It also helps you turn the machine on and off in a certain order. This diagram's goal is to make sure that all of the electrical parts work together safely and well and that the power and control parts work together perfectly.

There are two main circuits in the weaving machine for metal fencing: the power circuit and the control circuit. The power circuit carries electricity from the power source to the motor. The current goes through safety components like the circuit breaker and the thermal relay before reaching the contactor, which controls when the current is connected and disconnected from the motor.

The control circuit tells the machine when to start and stop. It uses simple parts like the Start and Stop buttons and the contactor's extra contacts to hold itself in place. This lets the motor keep going even after you press the start button [34].

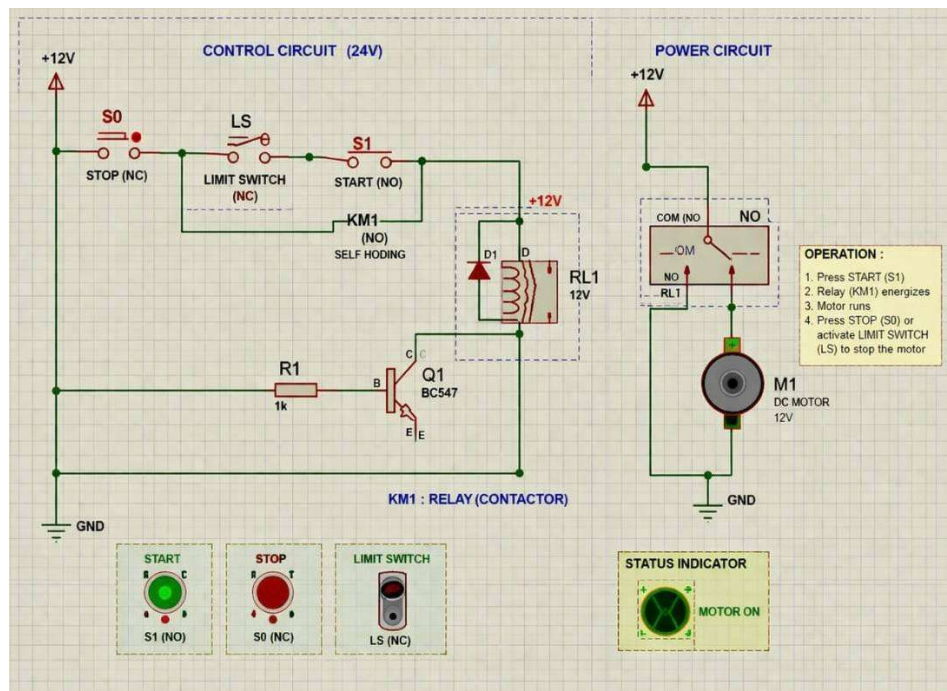


Figure 0-17 The electrical diagram of the machine [5]

III.8.2 ELECTRICAL CONTROL PANEL FOR a Semi-Automatic Chain Link Fence Machine

The electrical control panel is the most important part of the machine that weaves wire mesh by hand. It makes sure that power and control are clear and safe at every step of the process. The " Disconnecter," or main switch, is the first part of the system. It cuts off the power so that people can be safe while repairs or emergencies happen. The control system tells the contactor, the main part that turns the motor on and off, what to do with the current. A thermal relay is included to keep the motor from working too hard. This relay cuts off the circuit when the current rises for a set amount of time to keep the motor safe. There is also a counter on the display that is connected to an inductive proximity sensor. The sensor sends electrical signals to the counter when it sees the wire move or the number of cycles. Then the counter counts how many times the network was used or how long it was. This plan helps make production more accurate and keeps an eye on how things are going all the time. This setup is simple to use and works well because it combines power, protection, and control into one system that is easy to keep running and maintain. This method works well for businesses of all sizes [35].



A) Contactor



B) Disconnecter



C) Thermal Relay

Figure 0-18 A) Contact B) Disconnecter C) Thermal Relay [5]

III.8.3 Distance sensor

The BHM3-H Counter is a digital counter that is very popular in automation control systems. The BHM3-H Counter can read and count electrical pulses from different sensors and turn them into a digital number that can be displayed and processed. People often use this type of device to keep track of the number of cycles, parts made, or repeated actions of mechanical systems.

III.8.4 Principle of operation

The BHM3-H Counter gadget works by turning physical signals into electrical signals and then processing them digitally in the following order:

a) Making pulses:

A sensor, such as a photoelectric sensor, proximity sensor, or encoder, changes mechanical motion into electrical pulses, with each pulse standing for a different event.

b) Receiving a signal:

The meter gets these pulses through a specific input terminal, which changes the signal so that it can be processed digitally.

c) Counting and processing:

The internal processing unit raises the counter value by one for each pulse that comes in, as shown below.

$$N = \sum_{i=1}^k P_i \quad (0-10)$$

- N: Number of counted pulses
- P_i : The electrical pulse
- k: Total pulse count

d) Signal output:

The device turns on the relay output when $N = \text{Preset}$ is true. This output may be used to control things like motors or contactors.

III.8.5 Device components

- **Input:** For receiving pulses from the sensors
- **Processing Unit:** For processing signals and performing the counting operation
- **Display:** To display the current count value
- **Control Keys:** To adjust settings and reference values
- **Relay Output:** To send a signal when the desired count is reached

III.8.6 Industrial application

In the context of industrial systems, especially in the Chain Link Fence Machine, the counter is used to measure the number of cycles or turns resulting from the rotation of a specific axis. This is done by connecting a sensor to the rotation axis so that it generates an electrical pulse with each rotation [36].

Thus, the relationship between the number of pulses and the number of rotations can be determined as follows:

$$\textbf{Number of Revolutions} = \frac{\textbf{Number of Pulses}}{\textbf{Number of Pulses per Revolution}} \quad (0-11)$$

And by setting a specific value for the counter, the production process can be controlled, such as stopping the machine after a specified number of rotations to ensure length accuracy and product quality.

III.8.7 Sensor components

The primary role of the sensor is to serve as the "technical eye" that guarantees the precision of the fence dimensions and the safety of the machine by transforming mechanical movement into accurate digital control signals that eradicate human error.



Figure 0-19 Counter [5]



Figure 0-20 Proximity sensor [5]

III.9 Geometric calculations

III.9.1 Formative Forces Account

Bending wire is a necessary part of making metal fences. It changes the shape of the wire into the right helical shape by applying mechanical pressure. This process is called cold forming because it goes beyond the material's yield stress without breaking it.

The material's properties (like yield strength), the wire's shape (like its diameter), and the mold's bending radius all affect how much force is needed to shape it. When you bend the wire, the outside pulls apart and the inside pushes together. The length of the neutral axis stays the same.

To approximately calculate the forming strength, the following relationship can be used:

$$F = \frac{\sigma_y \cdot A}{k} \quad (0-12)$$

- F : Formative Force (Newton)•
- σ_y : Yield stress of the material (Pascals)
- A : Cross-sectional area of the wire (m²)
- k : Correction factor contingent upon bending circumstances (often ranging from 1.5 to 2)

Given that the wire possesses a circular cross-section, the cross-sectional area is determined using the formula:

$$A = \frac{\pi d^2}{4} \quad (0-13)$$

- Let (d) stand for the wire's diameter

The wire used in this project is made of low-carbon steel and has a yield stress of 200 to 300 megapascals. To ensure accurate calculations, an average value is used, and then a safety factor is added.

From a physical perspective, as the wire diameter increases, the cross-sectional area also increases. This means that a lot more force is needed to shape the wire (a quadratic relationship), which directly affects the choice of motor and transmission system. Furthermore, using a smaller die to decrease the bend radius increases the stresses, which means that the force needed must also increase [37].

III.9.2 Torque calculation

Torque is an important technical parameter in the design of the metal fence weaving machine because it shows how well the machine can bend wire and turn it into a helical shape. Torque is the effect of a force applied at a certain distance from the axis of rotation. That is what makes the machine's bending mechanism work. [38].

When you bend a wire, a mechanical force is applied to it at the point where it touches the bending tool (die). This makes the wire rotate around its axis. The amount of torque depends on how much force is applied and the radius of the bending tool

The following equation can be used to say this:

$$\mathbf{T = F \times r} \quad (0-14)$$

- T: Torque (Newton meter)
- F: The force applied to the wire (Newtons)
- r: The radius of the mold or bending tool (meter)

Practically, it is insufficient to depend solely on the theoretical torque value; one must also consider various factors influencing the system's actual performance, including friction among mechanical components and energy dissipation in the transmission system (gears or belts), as well as dynamic variations during operation. Consequently, a safety factor is typically employed to ensure that it is:

$$\mathbf{T_{motor} \geq T_{required} \times SF} \quad (0-15)$$

- T_{motor} : Motor torque
- $T_{required}$: The theoretically calculated torque
- SF: Safety factor

III.9.3 Calculation of the required power

It's very important to pick the right mold radius. A larger radius puts less stress on the wire, but it needs more torque. A smaller radius makes the wire less likely to bend, which makes it stronger and more torque. So, a good value is chosen to find a balance between how well it works and how malleable it is.

The torque calculation must match the speed of rotation because the machine's performance depends on the relationship between torque and speed. This can be explained as follow:

$$P = T \cdot \omega \quad (0-16)$$

- P: Power (Watt)
- T: Torque (Newton meter)
- ω : angular velocity (radians/second)

And because rotational speed is often given in revolutions per minute (RPM), it is converted to angular velocity according to the relationship:

$$\omega = \frac{2\pi N}{60} \quad (0-17)$$

- N: Rotational speed (revolutions/minute)

This link shows that the required power goes up when both torque and rotational speed go up. This means that the design process needs to carefully balance these two factors. The machine that weaves metal fences needs to go at a slow speed to keep the quality of the weaving high. The torque, which is a measure of the rotational force, is high because the wire doesn't bend easily, so the power needs to stay within a reasonable range.

The theoretically estimated power does not accurately reflect the actual power required by the motor due to mechanical losses in the system, such as friction in the bearings and energy loss in the transmission system (gears or belts), as well as the effects of unstable operation. Therefore, a correction factor is used that takes into account safety and efficiency factors. The following equation is used to determine the engine's real power:

$$P_{motor} = \frac{P}{\eta} \times K_s \quad (0-18)$$

- η : System efficiency (usually ranges between 0.8 and 0.9)
- K_s : Safety factor (ranging between 1.2 and 1.5)

This change makes sure that the engine keeps running without overloading, makes it last longer, and lowers the chance of problems.

Choosing the right power has a big effect on performance, energy use, and operational expenses. Choosing a motor with too much power wastes energy, and choosing one with too little power could cause the machine to break down or work less efficiently [39].

III.10 Component Classification and Specifications

To ensure reliability, cost-effectiveness, and ease of maintenance, the mechanical components of the semi-automatic chain-link fence machine are classified into two main categories: Standard (Off-the-Shelf) Components and Custom-Fabricated Parts.

III.10.1 Custom-Fabricated Parts

These parts are specifically designed and manufactured to meet the unique functional requirements of forming the wire mesh.

- **Forming Die (Weaving Screw):**

- **Function:** The central helical component that receives the wire and bends it into the required zig-zag diamond pattern.

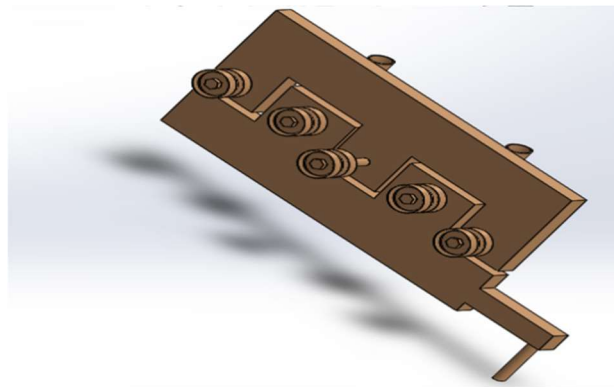


Figure 0-21 Weaving Screw

- **Winding Mandrel (Blade):**

- **Function:** The internal flat bar or blade inside the forming die around which the wire is twisted.

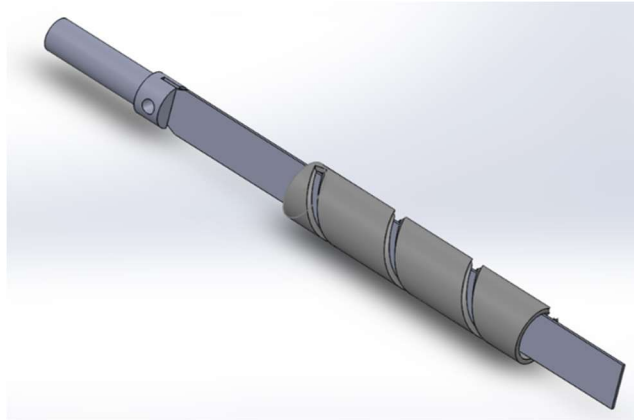


Figure 0-18 Winding Mandrel

- **Cutting Mechanism (Blades):**

- **Function:** Dynamically cuts the wire at the exact length once a full row of the fence is completed.

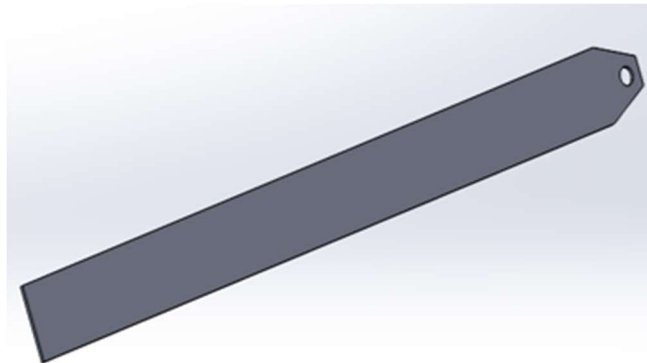


Figure III-19 Cutting Mechanism

- **Main Frame Structure:**

- **Function:** Represents the rigid backbone of the machine, supporting all moving elements and absorbing operational vibrations.



Figure 0-20 Main Frame Structure

III.11 Engineering Assembly and Bill of Materials:

III.11.1 Exploded and Fully Assembled Views

To illustrate the spatial relationship and integration of all mechanical components, both full assembly and exploded views of the semi-automatic chain-link fence machine were generated using CAD software. The 3D full assembly shows the final completed prototype with all systems synchronized, while the exploded view visualizes the internal alignment, structural stacking, and sequential mounting of the components (such as bearings, shafts, forming die, and motor).

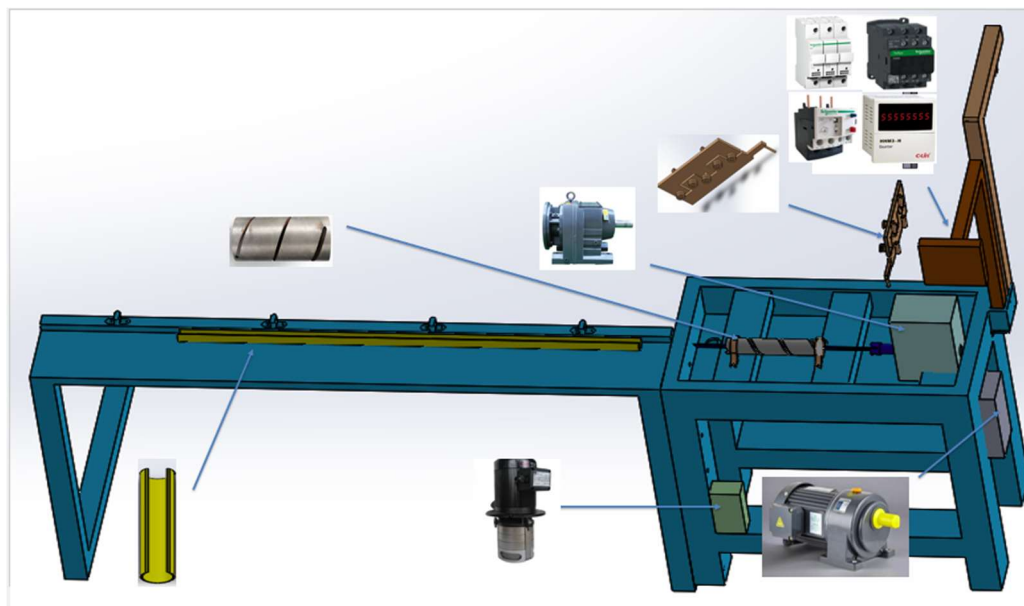


Figure 0-21 Exploded and Fully Assembled Views

III.11.2 . Bill of Materials (BOM)

The Bill of Materials (BOM) presented in Table 4.1 lists every standard and custom-fabricated part required to construct the machine. It provides a structured overview of part names, quantities, and material types used for proper documentation.

Table 0-1. Bill of Materials (BOM) for the Chain-Link Fence Machine

ITEM NO.	COMPONENT NAME	QUANTITY	MATERIAL / SPECIFICATION	TYPE
1	Main Frame Structure	1	Structural Steel St37 (Square Tube)	Custom
2	Electric Motor	1	[1.5 kW / 1440 RPM]	Standard
3	Gearbox / Speed Reducer	1	[Worm Gear 20:1 Ratio]	Standard
4	Pillow Block Bearings	[4]	[Cast Iron / Chrome Steel]	Standard
5	Drive Shaft	[1]	Medium Carbon Steel AISI 1045	Custom
6	Forming Die (Weaving Screw)	1	Hardened Tool Steel AISI D2	Custom
7	Winding Mandrel (Blade)	1	Medium Carbon Steel AISI 1045	Custom
8	Cutting Mechanism Blades	1	High-Speed Steel (HSS)	Custom
9	Drive Chain & Sprockets	[1 Set]	[Carbon Steel 0.5-inch Pitch]	Standard
10	Roller / Take-up Drum	1	Mild Steel St37	Custom

III.12 Machine Mechanism and Operational Sequence

The operational mechanism of the semi-automatic chain-link fence machine relies on the precise synchronization between the continuous rotational wire-forming system and the intermittent mechanical cutting system. The complete sequence of operation functions as follows:

1. **Wire Feeding and Helical Forming:**

The electric motor transmits rotational power through the gearbox to the main drive shaft. The galvanized steel wire is continuously fed into the stationary **Forming Die (Weaving Screw)**. As the shaft rotates, the wire wraps around the internal **Winding Mandrel**, forming a continuous zig-zag (diamond) pattern.

2. **Interlocking (Weaving Process):**

The newly formed zig-zag wire rotates out of the die and automatically screws into the loops of the previously formed wire strand, which rests on the long **Fence Receiving Table Frame**. This continuous interlocking creates the mesh structure.

3. **Length Detection and Intermittent Cutting:**

Once the wire strand reaches the required width of the fence, the rotation momentarily stops. The **Upper Cutter Support Arm** descends, activating the **Mechanical Cutting Blade** to shear the wire cleanly at the input end.

4. **Mesh Advancement:**

The completed section of the fence moves forward on the receiving table to clear space for the next wire strand, and the entire cycle repeats automatically.

III.13 conclusion

this chapter successfully detailed the engineering architecture and mechanical configuration of the semi-automatic chain-link fence machine. By classifying the system into standard components and custom-fabricated parts, the design guarantees a practical balance between manufacturability and cost efficiency. The integration of 3D CAD models, detailed 2D engineering projections, and a comprehensive Bill of Materials (BOM) provides the precise technical documentation required for physical prototype fabrication. Finally, mapping out the synchronized operational sequence ensures that the continuous weaving mechanism interacts seamlessly with the intermittent cutting system. The structural definitions established in this chapter provide a solid foundation for the upcoming experimental testing and performance evaluation.

General Conclusion

In conclusion, this memorandum establishes a comprehensive theoretical and engineering framework for the design and analysis of a semi-automatic wire fence weaving machine, successfully transitioning the manufacturing process from an empirical, trial-and-error approach to a disciplined scientific methodology grounded in advanced dynamic calculations and structural analysis. This study demonstrates that the development of high-efficiency industrial machinery relies fundamentally on the interdisciplinary integration of material mechanics, automated control theories, and manufacturing economics.

From a mechanical perspective, the study demonstrates that successful wire forming dictates a precise understanding of plastic deformation mechanics and the exact calculation of the stresses required to exceed the material's yield strength, while strictly preserving the integrity of the protective galvanized layer. This analytical approach provided the foundational baseline for estimating torque requirements, selecting high-efficiency power transmission systems, and ensuring the structural durability of the machine under varying operational loads.

In terms of operation and automation, the research highlights the critical role of electromechanical control circuits in achieving precise motion synchronization between the feeding and weaving units. The effective synthesis of these circuits ensures uniform mesh geometry, optimizes operational reliability in real-world production environments, and minimizes material waste.

This analytical framework is culminated by an economic feasibility study proving that optimal engineering design hinges on achieving a strategic equilibrium between capital expenditures (CAPEX) and operational expenditures (OPEX). The development of this semi-automatic machine represents a sustainable and cost-effective engineering solution tailored to enhance the productivity of small and medium-sized enterprises (SMEs).

Ultimately, this thesis serves as a robust academic foundation that can be extended in future research through the integration of fully automated digital control systems, thereby elevating product quality and advancing the competitiveness of the mechanical manufacturing sector.

Bibliography

1. “Manual vs Semi-Automatic vs Automatic Chain Link Fencing Machines – Simple Guide.”
2. “Chain Link Fencing Machine Overview || Manufactured Goods.”
3. “La Anneau De Chaîne Grillage Fabrication Machine | ECHOcommunity.org.”
4. I. B. Donham, “IE 431. 001 - Principles of Programmable Automation Course Syllabus: Fall 2013 Ag / IT 118A Fall 2013,” no. 2009, 2013
5. Kalpakjian, S., & Schmid, S. R. (2014). *Manufacturing engineering and technology* (7th ed.). Pearson Education.
6. Callister, W. D., & Rethwisch, D. G. (2020). *Materials science and engineering: An introduction* (10th ed.). John Wiley & Sons.
7. Hosford, W. F., & Caddell, R. M. (2011). *Metal forming: Mechanics and metallurgy* (3rd ed.). Cambridge University Press.
8. Groover, M. P. (2016). *Automation production systems and computer-integrated manufacturing* (4th ed.). Prentice Hall.
9. Nise, N. S. (2020). *Control systems engineering* (8th ed.). John Wiley & Sons.
10. Collins, J. A., Busby, H., & Staab, G. (2010). *Mechanical design of machine elements and machines* (2nd ed.). John Wiley & Sons.
11. Altan, T., Ngaile, G., & Shen, G. (2005). *Cold and hot forging: Fundamentals and applications*. ASM International.
12. Rao, S. S. (2018). *Mechanical Vibrations* (6th ed.). Pearson Education.
13. Shigley, J. E., & Mischke, C. R. (2014). *Mechanical Engineering Design* (10th ed.). McGraw-Hill Education.
14. Montgomery, D. C. (2012). *Introduction to Statistical Quality Control* (7th ed.). John Wiley & Sons.
15. Ridley, J., & Pearce, D. (2006). *Safety with Machinery* (2nd ed.). Butterworth-Heinemann.
16. International Organization for Standardization (ISO). (2010). *ISO 12100: Safety of machinery — General principles for design — Risk assessment and risk reduction*.
17. Bolton, W. (2015). *Programmable logic controllers*. Newnes.

18. Groover, M. P. (2019). *Fundamentals of Modern Manufacturing: Materials, Processes, and Systems* (7th ed.). Wiley.
19. Bridger, R. S. (2017). *Introduction to Human Factors and Ergonomics* (4th ed.). CRC Press.
20. Dhillon, B.S. (2011). *Safety of Machinery: Risk Assessment and Risk Reduction*. CRC Press
21. Tricker, R. (2016). *Quality Management Systems: A Practical Guide to ISO 9001:2015*. Routledge.
22. Bringas, J. E. (2016). *Handbook of Comparative World Steel Standards*. ASTM International.
23. Sullivan, W. G., Wicks, E. M., & Koelling, C. P. (2018). *Engineering Economy*. Pearson Education.
24. Brauer, R. L. (2016). *Safety and Health for Engineers*. 3rd Edition, Wiley
25. “Ward, S. W. (2006). *Chain-link fencing: Design, management and maintenance*. Taylor & Francis.
26. F. Chiarello, P. Belingheri, and G. Fantoni, “Data science for engineering design: State of the art and future directions,” *Comput. Ind.*, vol. 129, p. 103447, Aug. 2021, doi: 10.1016/J.COMPIND.2021.103447.
27. J. Tilbury and S. Flowerday, “Humans and Automation: Augmenting Security Operation Centers,” *Journal of Cybersecurity and Privacy*, vol. 4, no. 3, pp. 388–409, Sep. 2024, doi: 10.3390/JCP4030020/S1.
28. “Search results: mechatronics electronic control systems in mechanical and electrical engineering | Pearson GB
29. R. G. Budynas and J. Keith Nisbett, “Shigley’s Mechanical Engineering Design 10th Edition”.
30. S. Chapman, “Electric Machinery Fundamentals (McGraw-Hill Series in Electrical and Computer Engineering) 4th Edition,” p. 744, 2013
31. A. Varghese, S. Martins, E. Lessing, G. M. Hassan, and A. Karrech, “A systematic review on the sustainability of slurry pumps in the mining industry,” *Miner. Eng.*, vol. 234, p. 109731, Dec. 2025, doi: 10.1016/J.MINENG.2025.109731.
32. Grosman, F., & Tkocz, M. (2015). *Analysis of the wire feeding process in forming machines*. Journal of Materials Processing Technology.

33. Groover, M. P. (2020). *Fundamentals of Modern Manufacturing: Materials, Processes, and Systems*. Wiley.
34. Bridger, R. S. (2017). *Introduction to Ergonomics*. CRC Press. Taylor & Francis Group.
35. Petruzella, F. D. (2016). *Electric Motors and Control Systems* (2nd ed.). McGraw-Hill Education.
36. Bartelt, T. L. (2012). *Industrial Control Electronics: Devices, Systems, and Applications*. Cengage Learning.
37. De Silva, C. W. (2015). *Sensors and Actuators: Engineering System Instrumentation, Second Edition*. CRC Press.
38. Manufacturing Engineering and Technology
39. Kalpakjian, S., & Schmid, S. (2014). *Manufacturing Engineering and Technology* (7th ed.). Pearson
40. Shigley, J. E., & Mischke, C. R. (2014). *Mechanical Engineering Design*. McGraw-Hill Education.
41. Nise, N. S. (2020). *Control Systems Engineering*. John Wiley & Sons.
42. Kalpakjian, S., & Schmid, S. R. (2014). *Manufacturing Engineering and Technology*. Pearson Education.

Bibliography of figures:

- 1.** Groover, M. P. (2020). *Fundamentals of Modern Manufacturing: Materials, Processes, and Systems*. Wiley
- 2.** Grosman, F., & Tkocz, M. (2015). *Analysis of the wire feeding process in forming machines*. Journal of Materials Processing Technology.
- 3.** De Silva, C. W. (2015). *Sensors and Actuators: Engineering System Instrumentation* (2nd ed.). CRC Press.
- 4.** Petruzella, F. D. (2016). *Electric Motors and Control Systems* (2nd ed.). McGraw-Hill Education.
- 5.** Bartelt, T. L. (2012). *Industrial Control Electronics: Devices, Systems, and Applications*. Cengage Learning.