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Thème

Study of an automatic stirrup bending machine

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DEDICATION

I would like to dedicate this work to my beloved parents, the most important persons in my life for their support, encouragement, and sacrifice all the way long.

special thanks to my brothers Adel, Achref And Badri and my lovely sister for their endless support, and encouragement and for standing by my side from the beginning to the end of this work

Aymen

DEDICATION

This work is dedicated to my beloved parents for their endless love and Support.

My beloved brothers and my lovely sister who has a great impact on my thesis

To my intimate friends Akrem, Anis and Nassim

Special thanks go to the people who believed in me and helped me in difficult times in my life Mr Rabhi Boudjema and Mr Gasmi Rachid, Thank you all.

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ABSTRACT

The primary objective of our research is to conduct a study and preliminary design of a stirrup machine capable of shaping different types of stirrups using an 8mm rebar. The process of shaping stirrups involves various mechanisms, including feeding, bending, and cutting the rebar. Each mechanism requires precision and careful consideration to ensure synchronization with each other. Therefore, it was essential to connect all these mechanisms with an automated controller and use stepper motors for that purpose. Additionally, in order to develop a clear understanding of the machine, we used software programs such as SolidWorks for the designing, WinProladder for writing ladder code and EasyBuilder Pro for designing and programming HMI (Human Machine Interface) screens

KeyWords: winproladder, solidworks, PLC, stirrups, bending, rebar, stepper motor, HMI,

RÉSUMÉ

L'objectif principal de notre recherche est de réaliser une étude et une conception préliminaire d'une machine à étriers capable de façonner différents types d'étriers à l'aide d'une barre d'armature de 8 mm. Le processus de façonnage des étriers implique divers mécanismes, notamment l'alimentation, le pliage et la coupe de la barre d'armature. Chaque mécanisme nécessite une précision et une attention particulière pour assurer la synchronisation les uns avec les autres. Par conséquent, il était essentiel de connecter tous ces mécanismes à un contrôleur automatisé et d'utiliser des moteurs pas à pas à cette fin. De plus, afin de développer une compréhension claire de la machine, nous avons utilisé des logiciels tels que SolidWorks pour la conception, WinProladder pour l'écriture du code à contacts et EasyBuilder Pro pour la conception et la programmation des écrans HMI (Human Machine Interface).

Mots clés : winproladder, solidworks, PLC, étriers, flexion, barres d'armature, moteur pas à pas,HMI,

مخلص

الهدف الأساسي لبحثنا هو إجراء دراسة وتصميم أولي لآلة تشكيل الكانات قادرة على تشكيل أنواع مختلفة من الكانات باستخدام حديد التسليح 8 مم. تتضمن عملية تشكيل الكانات آليات مختلفة ، بما في ذلك التغذية والثني وقطع حديد التسليح. تتطلب كل آلية دقة و دراسة متأنية لضمان التزامن مع بعضها البعض , لذلك كان من الضروري توصيل كل هذه الآليات بوحدة تحكم آلية واستخدام محركات السائر لهذا الغرض. بالإضافة إلى ذلك ، ومن أجل فهم واضح للآلة ، استخدمنا برامج مثل SolidWorks للتصميم , WinProladder, لكتابة كود البرمجة , EasyBuilder Pro لتصميم وبرمجة شاشات التحكم

الكلمات المفتاحية:winproladder, solidworks, HMI,PLC ركاب,ثني,حديد التسليح,محرك خطوي

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GENERAL INTRODUCTION

With the increasing population and the continuous demand for housing construction, a significant gap has emerged between the rate of housing production and the rate of demand. This disparity can be attributed to the large amount of time and effort invested by construction workers in certain stages of the construction process, making it challenging for them to meet the demand. To address this issue, stirrup machines were invented to alleviate one of the main problems faced by construction workers. These machines enable the production of a large number of stirrups in a short period of time with high speed and efficiency.

However, Algerian construction workers still encounter challenges due to the lack of stirrup machines in the local market. Importing these machines is often impractical and costly. Therefore, the thesis was inspired by these circumstances, aiming to study and preliminarily design a locally manufactured stirrup machine that is affordable, economical, and specifically tailored to meet the requirements of Algerian construction workers.

LITERATURE REVIEW

1- Design, Development and Fabrication of Stirrup Making Machine Energized by Human Powered Flywheel Motor [1]

In this research the authors designed, developed and fabricated a stirrup making machine that energized by Human Powered Flywheel Motor (HPFM), in order to bend round bar. The desired speed can be obtained by the operator through a chain and a pair of gears.

2- DESIGN AND FABRICATION OF MULTIROD BENDING MACHINE [2]

they present a design and fabrication of mult-irod bending machine that use a hydraulic power of fluid. The process of bending is done with two hydraulic cylinders, one of them is for bending operation and the another one is for feeding the rod for the next bent. The movement of piston is controlled by control valve. The machine can make different shapes and sizes by varying the die specification in order to produce one stirrup.

3- Design and Fabrication of Pneumatically Operated Bar Bending Machine [3]

This study is focusing on design and Fabrication of Pneumatically operated Bar Bending Machine. The machine is capable of making stirrups by bending FE500 iron rod in square shapes its worth mentioning that the machine is semi-automatic since the operator is loading and unloading the bar manually and the bending of the rod is done pneumatically.

4- DESIGN AND FABRICATION OF PNEUMATIC BAR BENDING MACHINE [4]

This paper is aimed at bending 8-mm rods into square stirrups using a pneumatic system. The working principle of that machine is to bend the rod with the pneumatic cylinder piston by holding the rod in the fixture. While this rode is being fed automatically with the help of a motor and pulley arrangement

5- Automatic Rebar Bending Machine to Form Rectangular Stirrups [5]

This project considers design and building an automatic rebar bending machine to form square stirrups with different dimensions. The machine aims to form closed loop stirrups from 8mm steel rebars without needs human assist. the machine automatically inserts the bar then bend it to the required stirrup dimensions based on the algorithm build in Programing Logic Controller (PLC). the dimensions of stirrups can be controlled via Human Machine Interface (HMI)

CHAPTER I INTRODUCTION TO STIRRUP MACHINE

I.1 CONSTRUCTION REBARS

I.2 REBARS MATERIALS

I.3 STIRRUPS

I.4 THE IMPORTANCE OF STIRRUPS

I.5 STIRRUPS TYPES

I.6 PROCESS OF SHAPING STIRRUPS

I.7 SHAPING STIRRUPS METHOD

I.1 CONSTRUCTION REBARS

Steel is an alloy of iron and carbon. The carbon content, or proportion, varies from 0.1 to 2%. Steel can be used independently in conventional metal construction (bridges, warehouses, and building frameworks) or to compensate for the insufficient tensile strength of concrete in reinforced concrete or restressed concrete.

Steel possesses a set of remarkable mechanical properties: high tensile and impact strength, good elasticity, and excellent hardness, which ensure its increasingly widespread applications. [6]

I.2 REBARS MATERIALS

Rebars can be classified in to 3 main types as follows

I.2.1 Round bar :

A round bar is a smooth-surfaced steel bar used when strength and durability are not major concerns. Common material options for round bars include FeE 215, FeE 235, FeE 400, and FeE 500. The used diameters are 6, 8, 10, and 12 mm.. [7]

Figure I-1: round bar

I.2.2 deformed bars :

Deformed bars are steel bars that have surface projections and indentations within them. This type of rebar is widely used in applications where strength and durability are paramount. The material of deformed bars can be one of the following: FeE400, FeE500. The commonly used round bar diameters are 6, 8, 10, 12, 14, 16, 20, 25, 32, and 40 mm.. [8] [7]

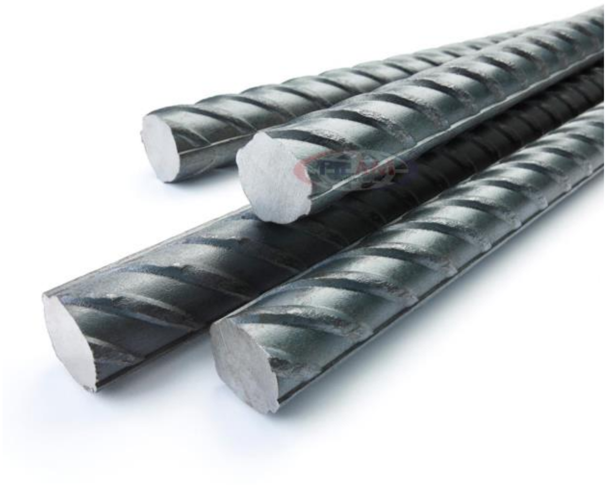


Figure I-2: deformed bar

I.2.3 Welded wire mesh

Welded wire mesh is a series of wires that are welded where the individual wires cross. The openings of the mesh vary depending on the type of wire used and the function of the mesh. Regardless of size and wire, welded wire mesh is permanent and impossible to deconstruct without using extreme force.

- The material of welded wire mesh bars can be one of the following: FeTE500, TSL500
- The commonly used welded wire mesh diameters are as follows:
  - Smooth welded meshes (TSL): 3.5 to 9 mm with a pitch of 0.5 mm.
  - High-adhesion welded meshes (TSHA): 3.5 to 12 mm with a pitch of 0.5 mm [7] [9]

Figure I-3: Welded wire mesh

The following table summarizes the properities of rebars used in reinforcement:

Grade	Minimum yield strength (MPa)	Minimum tensile strength(MPa)	Density (Kg/m^3)
FeE215	215	330	7800
FeE 235	235	410	
FeE 400	400	480	
FeE 500	500	550	

Table I-1: Rebar properities [7] [10] [11]

I.3 STIRRUPS

Stirrups are closed loops of steel bar used in reinforced concrete structures. They hold reinforcement bars together in foundational beams and columns.

Figure I-4: stirrup

I.4 THE IMPORTANCE OF STIRRUPS

There is a very important role for stirrups in a beam or column. The stirrups are used for the reasons given below:

- Stirrups are used to resist the lateral shear stress in the reinforced roncrete structure.
- They are used to resist the diagonal tension stress in the reinforced concrete structure.
- They prevent the formation of inclined shear cracks.
- They are used to prevent the buckling of compressive stress-bearing structures like columns, struts, etc. [12]

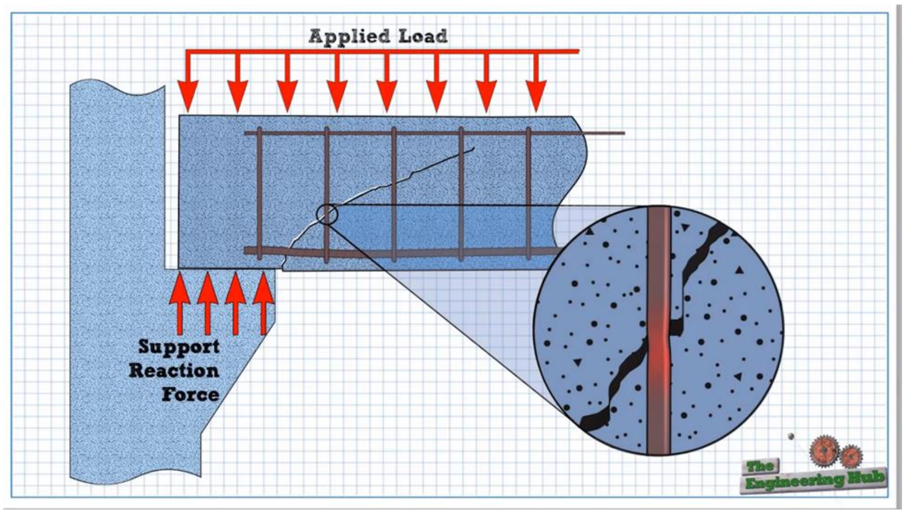


Figure I-5: crack in beams [13]

I.5 STIRRUPS TYPES

The widely used stirrups in reinforcement can be classified according to their shape as follows:

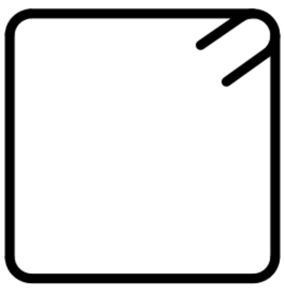
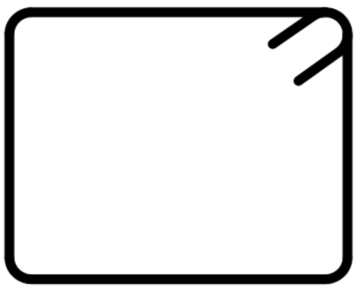
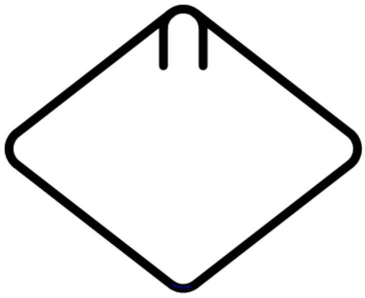
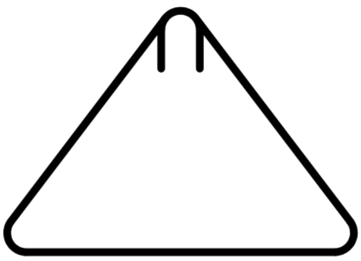
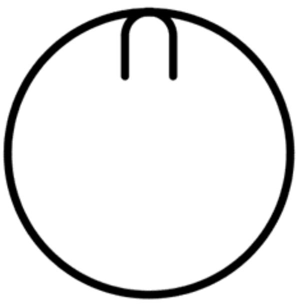
		
Square stirrup	Rectangular stirrup	Diamond stirrup
		
Triangular stirrup	Circular Stirrup	Pin stirrup

Table I-2 : stirrups types

I.6 PROCCES OF SHAPING STIRRUPS

The process of shaping the stirrups takes two main steps: cutting and bending.

- Cutting

The rebar with a diameter of 8 mm comes with a length of 12 meters, so the first step that the construction worker takes is to manually measure the length of the rebar and then cut it using tools or machines that were built for that purpose.

Figure I-6: manually rebar cutting [14]

- Bending

After cutting the rebar into a specified length, the construction worker starts bending the rebar according to the required shape using manual tools or electric benders, relying on the human eye to determine the angle of the bend or with the help of semi-automated benders that bend it at the required angle.

Figure I-7: manually rebar bending [15]

I.7 SHAPING STIRRUPS METHODS

Stirrups can be shaped using manual tools or semi-automatic machines that perform one step of the stirrup shaping process, whether it's bending, cutting, or straightening the rebar used in shaping the stirrups. In addition to that, there are automatic machines that perform the full process of stirrup shaping.

I.7.1 Manual stirrup machines

- **Manual rebar benders**

Manual rebar benders are simple bending tools used in the construction industry for many years. They are devices designed to cut and bend steel reinforcement bars (rebars) into the desired shape, enabling workers to create precise and uniform-radius bends without excessive effort. These tools come equipped with a bending die, allowing for efficient shaping of the rebars for use in various industrial applications. Manual rebar benders are known for their ease of operation and have been widely used in the concrete construction industry for their reliability and versatility. [16] [17] [18]

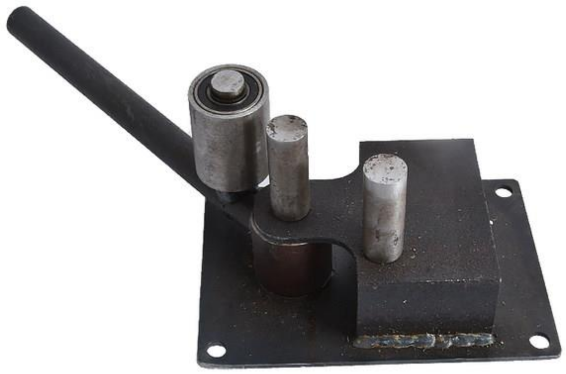


Figure I-8: manual rebar bender

- **Manual rebar cutter**

A rebar cutter is a specialized tool used in the construction industry to cut steel reinforcement bars (rebars) for building structural reinforcement in concrete work. It finds application in various industrial settings, facilitating the precise and efficient cutting of rebars to desired lengths. The cutting process is particularly challenging when dealing with thick rebars, requiring the use of specialized tools to ensure safety and ease. By employing a cutting blade or shear mechanism, rebar cutters enable the safe and accurate preparation of rebars. [17] [19]

Figure I-9: manual rebar cutter

I.7.2 Semi-automatic stirrup machines

- **Portable Rebar cutter**

A portable rebar cutter is a compact and mobile tool used for cutting reinforcing steel bars. It offers efficient and precise cutting of rebar in construction and steel fabrication projects. These tools are designed to be lightweight and easy to transport on job sites. They feature sharp cutting blades and adjustable cutting depths to accommodate different rebar sizes. Portable rebar cutters enhance productivity and accuracy while reducing manual effort and the need for additional finishing work. [19]

- **Portable Rebar Bender**

A portable rebar bender, whether electric or hydraulic, is a versatile tool capable of executing rebar bends accurately without compromising the strength of the metal rods. These benders are designed to be easy to use and carry, making them ideal for reinforced concrete construction projects. They allow for precise bending of rebars at various angles, meeting the specific design needs. Portable benders have the capability to bend different sizes and grades of rebar, providing flexibility in construction applications. [19]

Figure I-10: portable rebar bender

- **Electric Rebar Bender**

Electric rebar benders are widely used in reinforced concrete construction and can bend rebars in various arcs and angles on the basis of design needs. Electric benders are able to bend different sizes and grades of rebar. This type of bender is electrically powered and convenient to use. [19]

Figure I-11: electric rebar bender

- **Hydraulic Rebar Bender**

A hydraulic rebar bender is a type of bender that applies hydraulic force to bend the steel bars. This type of bender also provides flexibility and is easy to operate. Different sizes and diameters of rebar that range from 4 mm to 60 mm can be bent using a hydraulic rebar bender. This bender bends the steel bars uniformly and accurately. [19]

Figure I-12: hydraulic rebar bender

I.7.3 automatic stirrup machines

- **automatic rebar bender**

An automatic rebar bender is a type of bender that provides the benefit of automatic numerical control, which automatically adjusts gears, providing easy switching between the desired bending angles. It is easy to use and contains numerical control panels that provide accurate rebar bending. [19]

Figure I-13: automatic rebar bender

- **automatic Stirrup Bending Machine**

An automatic stirrup machine is advanced equipment that offers more than just bending the rebar to become a stirrup. This automatic bending machine can also straighten and cut steel bar as it is being bent to its desired bent anchorage. The automatic stirrup machine can produce many and accurately made stirrups in a short span of time. [20]

Figure I-14: automatic Stirrup Bending Machine

I.8 STIRRUP DIMENSIONS

Based on the information we have collected from civil engineers; we can provide the following instructions:

- There are different types of rebar in the Algerian market, which are classified based on the diameters and the mechanical properties of the rebar's material.

- The minimum bending radius for stirrups is 6 mm, and that radius is based on the minimum diameter of the reinforcement bars, which have a diameter of 12 mm.

- The minimum diameter of rebar that is used in stirrups is 8 mm.

- The minimum dimensions of the stirrups are (23×23) cm.

- The length of the stirrup hooks is based on their bending degree and the diameter of the stirrup rebar.

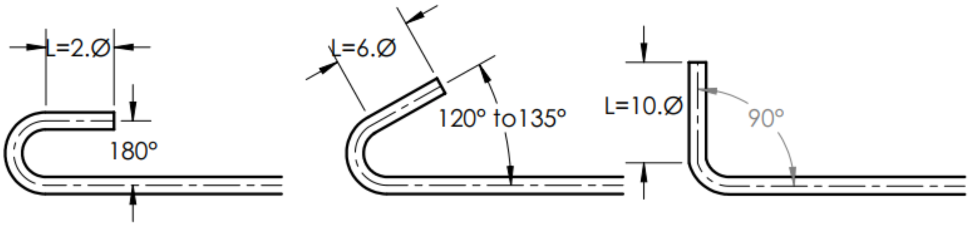


Figure I-15: hook length [6]

While L is the length of the hook and ø is the diameter of the stirrup rebar .

I.9 PROJECT OVERVIEW

I.9.1 Identifying the needs

The machine must meet the following conditions:

- The machine should be capable of shaping rectangle, triangle, and pin stirrup shapes.
- The machine should have a simple control interface that allows the worker to select the shape, determine the dimensions, and specify the required quantity.
- The production speed of each stirrup should be less than 15 seconds.
- The length of the stirrups sides should be between 23 cm and 50 cm.

I.9.2 List of requirements

- Electric linear actuators (x2).
- Electrohydraulic linear actuator.
- Programmed logic control unit (PLC).
- Touch screen (HMI).
- Stepper motors (x2).
- Stepper motor drivers (x2).
- Stepper motor gearbox
- Power supply.
- Sensors

CHAPTER II PRELIMINARY DESIGN

II.1 INTRODUCTION

II.2 MACHINE COMPONENTS

II.3 PROCCESSING DETAILS OF EACH PART

II.4 WORKING PRINCIPLES OVERVIEW

II.5 FUNCTIONAL DIMENSIONS

II.1 INTRODUCTION

The conceptual design phase is one of the most important stages, where a clear vision for the project is developed. It involves evaluating possible solutions to determine the best solution that meets the project's requirements. In this chapter, we will discuss the machine parts in detail, the components, and the working principle of each part in all stages that the rebar goes through until it is shaped as a stirrup.

II.2 MACHINE COMPONENTS:

II.2.1 Stepper motor

A stepper motor is a type of DC motor that works in discrete steps. It is a synchronous brushless motor where a full rotation is divided into a number of steps. The two main components of a stepper motor are the rotor and the stator. The rotor is the rotating shaft, and the stator consists of electromagnets that form the stationary part of the motor. When a discrete DC voltage is applied, the stepper motor rotates at a particular angle called the step angle; thus, a stepper motor is manufactured with steps per revolution of 12, 24, 72, 144, 180, and 200, with a corresponding step angle of 30, 15, 5, 2.5, 2, and 1.8. It can be operated with or without a feedback control. [21]

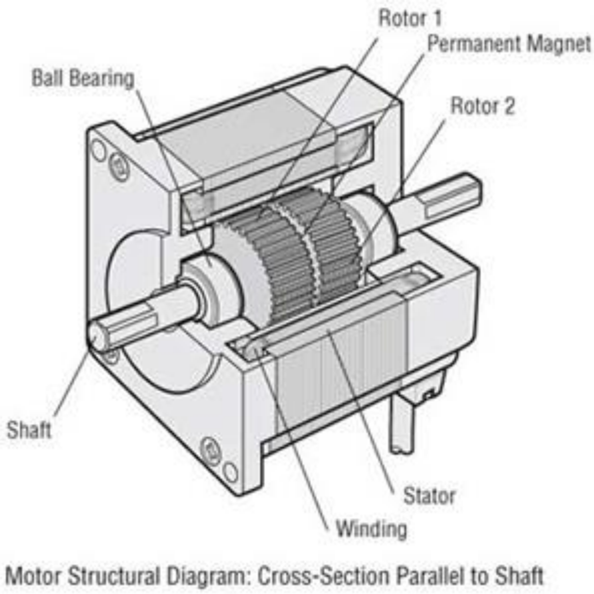


Figure II-1: stepper motor

II.2.2 Gearbox

A gearbox is a mechanical device that is used to increase the output torque or change the speed (RPM) of the motor. The motor shaft is connected to one end of the gearbox, and through the internal configuration of the gears of the gearbox, it provides an output torque and a specific speed determined by the gear ratio. [22]

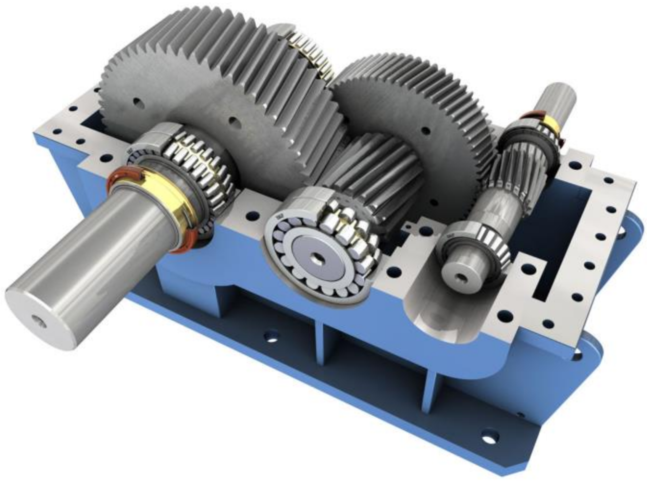


Figure II-2:gearbox

II.2.3 stepper driver

A stepper motor driver is an actuator that can transform a pulse signal into an angular displacement signal. Stepper motor drivers drive stepper motors to rotate at an angle called the step angle in the set direction when receiving a pulse signal. The motor speed is up to the pulse frequency given from the controller, and the displacement is decided on the pulse quantity given from the controller. A stepper system consists of a stepper motor and a stepper driver. The performance of a stepper system is not only up to the motor but also depends on the stepper driver. [31]

Figure II-3: stepper driver

II.2.4 Guide slides

Linear guides, or linear rail slides, are support devices that are used to help carry loads and ensure straight and level linear motion. Linear guides will usually consist of two components: the sliding carriage and the rail. The sliding carriage is the element that moves along the rail and supports the attached load. [24]

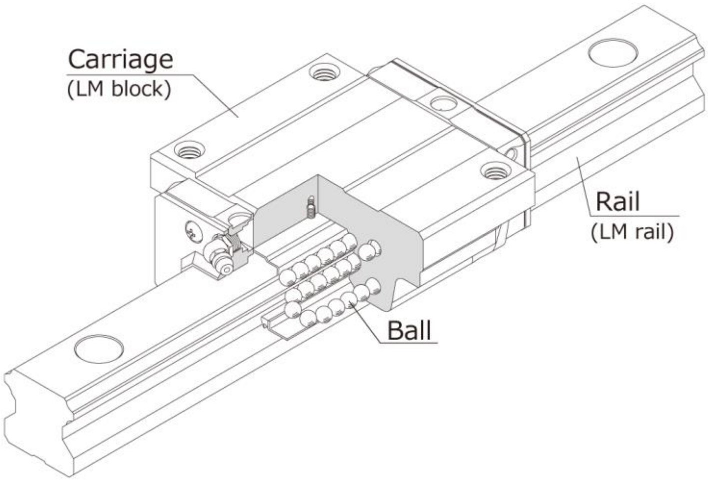


Figure II-4: Guide slides

II.2.5 Rack and pinion

A rack and pinion comprises a pair of gears that convert rotational motion to linear motion and vice versa. This is commonly used in the steering systems of small trucks and SUVs, other than in lifting mechanisms, machine tools, etc. [25]

Figure II-5: Rack and pinion

II.2.6 Linear actuators

An electric linear actuator is an electromechanical device mainly composed of a motor, a set of gears, and a motion mechanism in the form of a worm and tube. It converts the motor's rotary motion into linear motion by driving the gears and worm gear. [26]

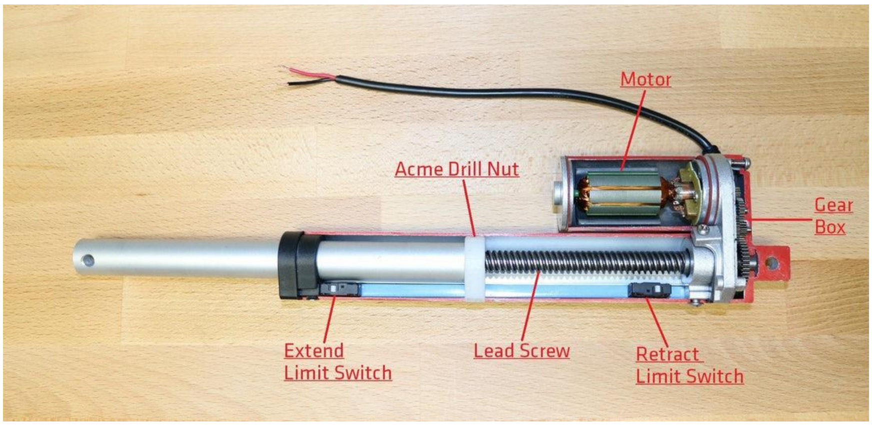


Figure II-6: linear actuator

II.2.7 PLC

A programmable logic controller is a type of tiny computer that can receive data through its inputs and send operating instructions through its outputs. Fundamentally, a PLC's job is to control a system's functions using the internal logic programmed into it. Businesses around the world use PLCs to automate their most important processes. [27]

Figure II-7: PLC

II.2.8 Power supply

A power supply is an electrical device that offers electric power to an electrical load such as a laptop computer, server, or other electronic device. The main function of a power supply is to convert electric current from a source to the correct voltage, current, and frequency to power the load. [28]

Figure II-8: power supply

II.2.9 Sensors

A sensor is a device that detects and responds to some type of input from the physical environment. The input can be light, heat, motion, moisture, pressure, or any number of other environmental phenomena. The output is generally a signal that is converted to a human-readable display at the sensor location or transmitted electronically over a network for reading or further processing. [29]

Figure II-9: sensor

II.3 PROCESSING DETAILS OF EACH PART

The machine contains several mechanisms working together to achieve its main purpose.

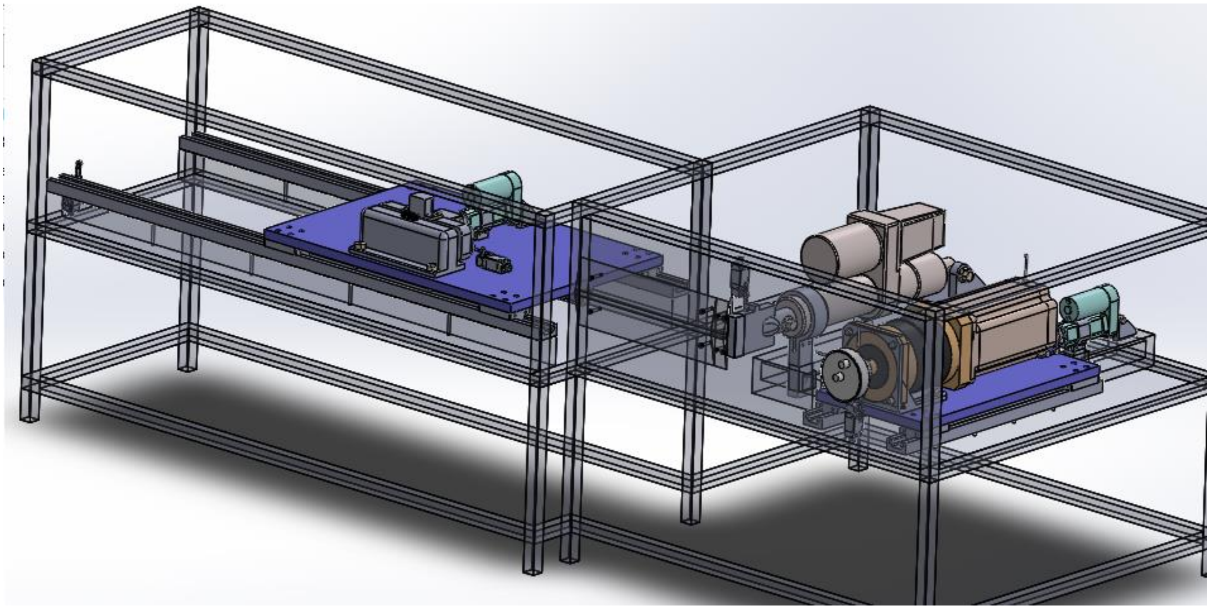


Figure II-10: full machine

The machine mechanisms are as follows:

II.3.1 Feeding mechanism :

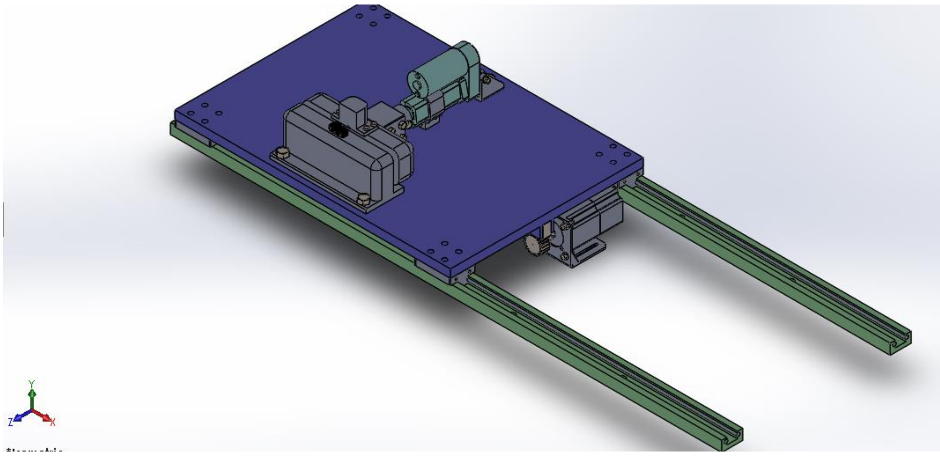


Figure II-11: feeding mechanisms

The feeding mechanism is used to grip the rebar and then feed it to the next stage in a linear way.

- The gripping part

which is a linear actuator that grips the rebar during the feeding process.

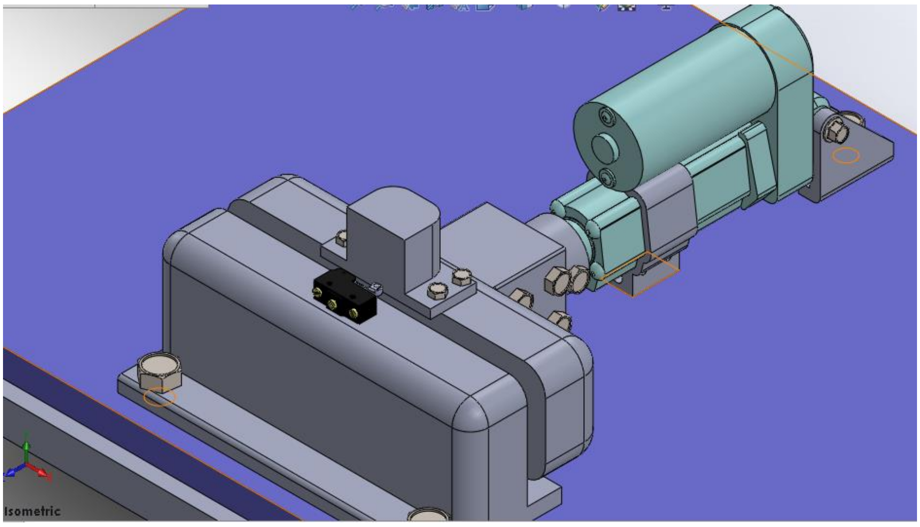


Figure II-12feeding mechanism gripping part

- Transition part

which is a stage that the gripping part is mounted on. This stage moves on a horizontal guide using a rack and pinion mechanism.

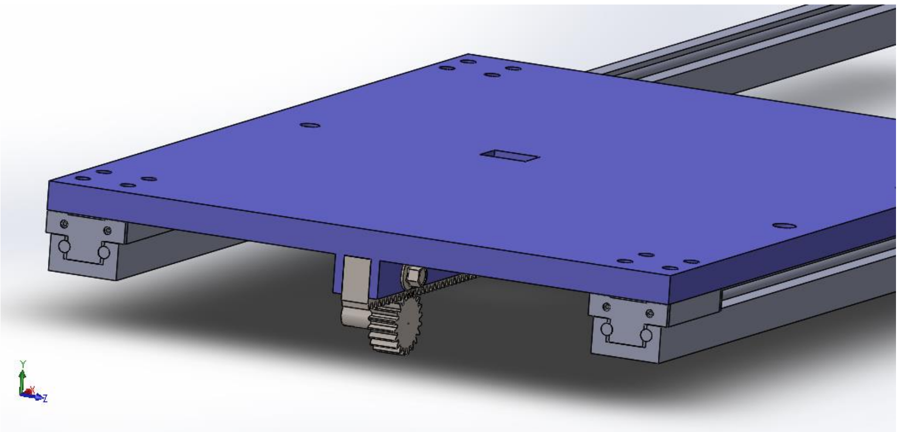


Figure II-13: feeding mechanism transition part

- Feeding part

To achieve the specified lengths without the need for feedback, we chose a stepper motor to meet that purpose.

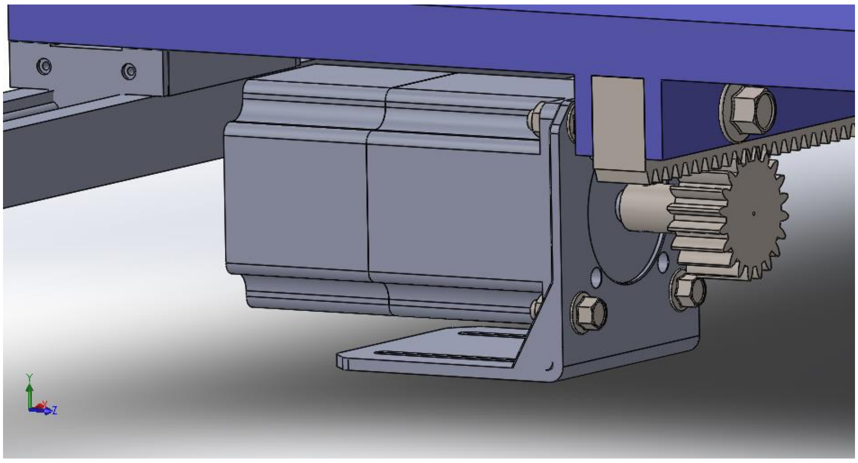


Figure II-14: feeding mechanism feeding part

II.3.2 Bending mechanism :

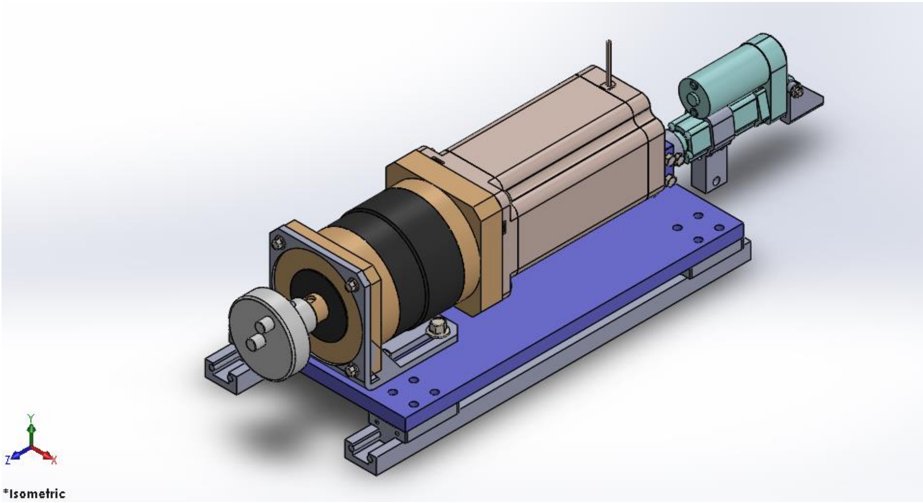


Figure II-15: bending mechanism

This mechanism bends the rebar using the bending disc with the necessary force and angle. The bending mechanism consists of three parts.

- **Bending disc**

The bending disc has two pins, a fixed pin and a rotating one; the fixed one is used to bend the rebar on it, while the other one is responsible for the bending.

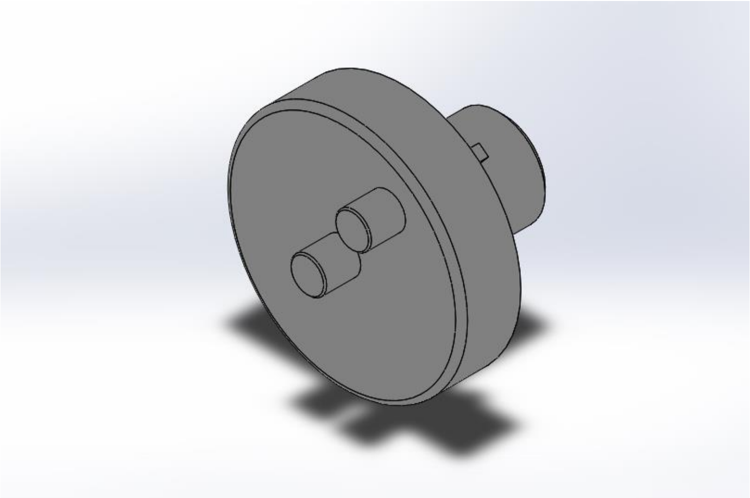


Figure II-16: bending disc

- **Feeding part**

This includes a stepper motor that provides the bending disk with the precise rotational angle in addition to the required force by increasing the torque using a gearbox.

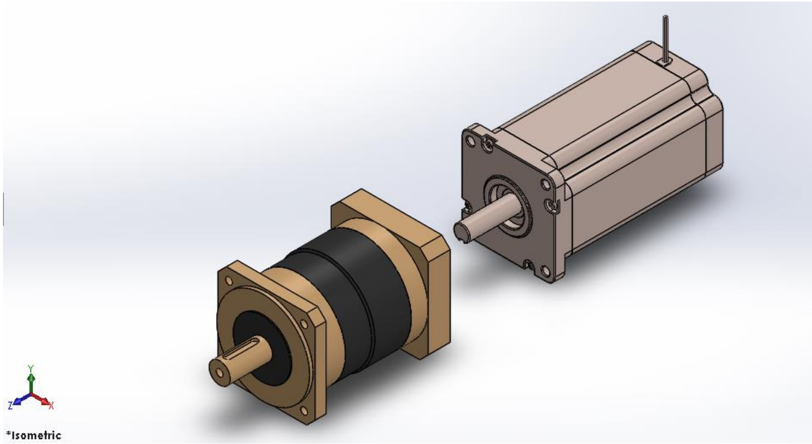


Figure II-17: bending mechanism feeding part

- **Transition part**

In this part, we need to pull the bending mechanism backwards at certain steps to enable the mechanism to complete the bending stages smoothly without getting stuck. The transition part contains a table that moves linearly using a linear actuator, while the following components are mounted on it: the stepper motor the gearbox and the bending disc.

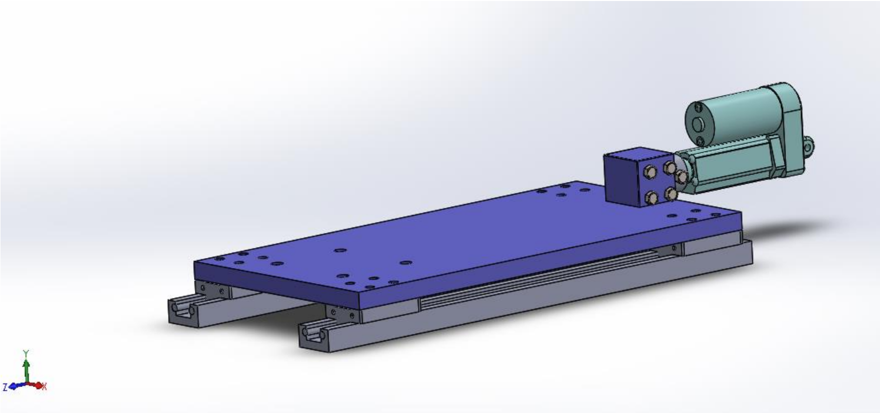


Figure II-18: banding mechanism transition part

We need an extra part in our mechanism that is used to prevent the rebar from touching its tail in certain steps of the bending process. We will call it the lifting part.

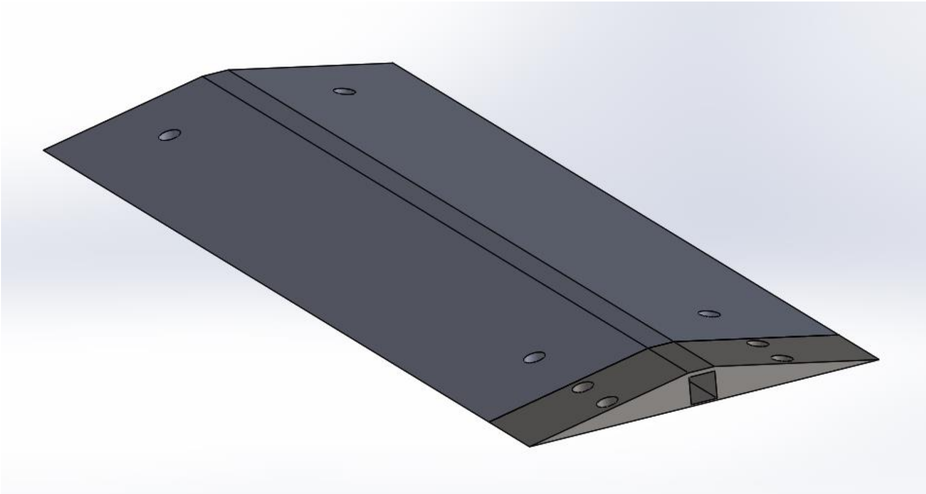


Figure II-19: lifting part

II.3.3 Cutting mechanism:

Which is an electro-hydraulic linear actuator using a high force to shear rebar.

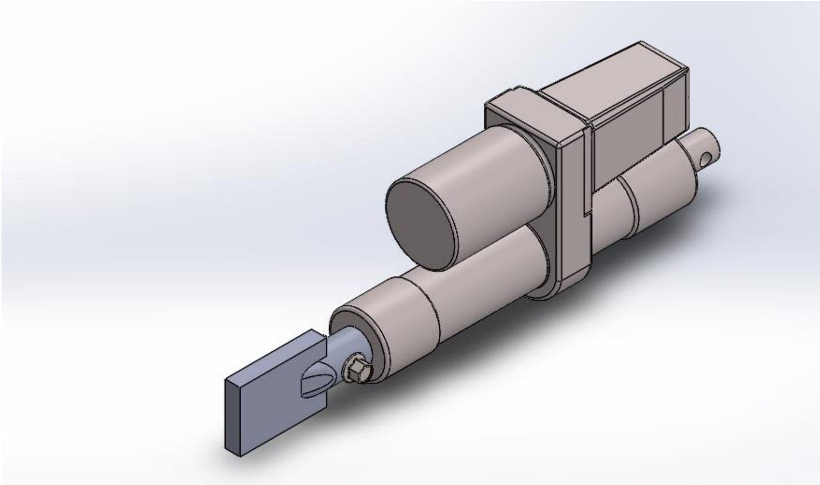


Figure II-20: cutting mechanism

II.4 WORKING PRINCIPLES OVERVIEW

This section includes an overview of the machine's working principle, step by step.

Let's take a rectangle stirrup as an example.

1) The operator manually pulls the rebar and feeds it through the feeding mechanism until it reaches the edge of the lifting part.

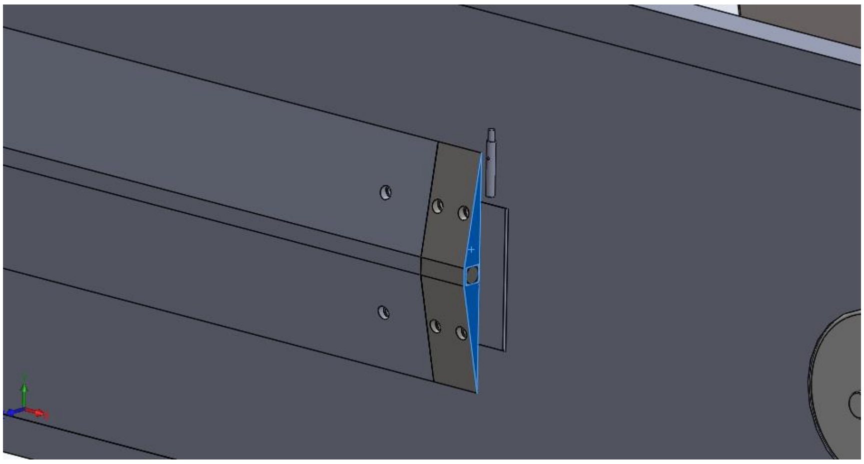


Figure II-21: rebar initial position

2) The operator selects the desired shape from the screen and then presses next, as shown in the picture below.

3) The operator inserts the selected shape dimensions, followed by the desired quantity to be produced, and presses Start.

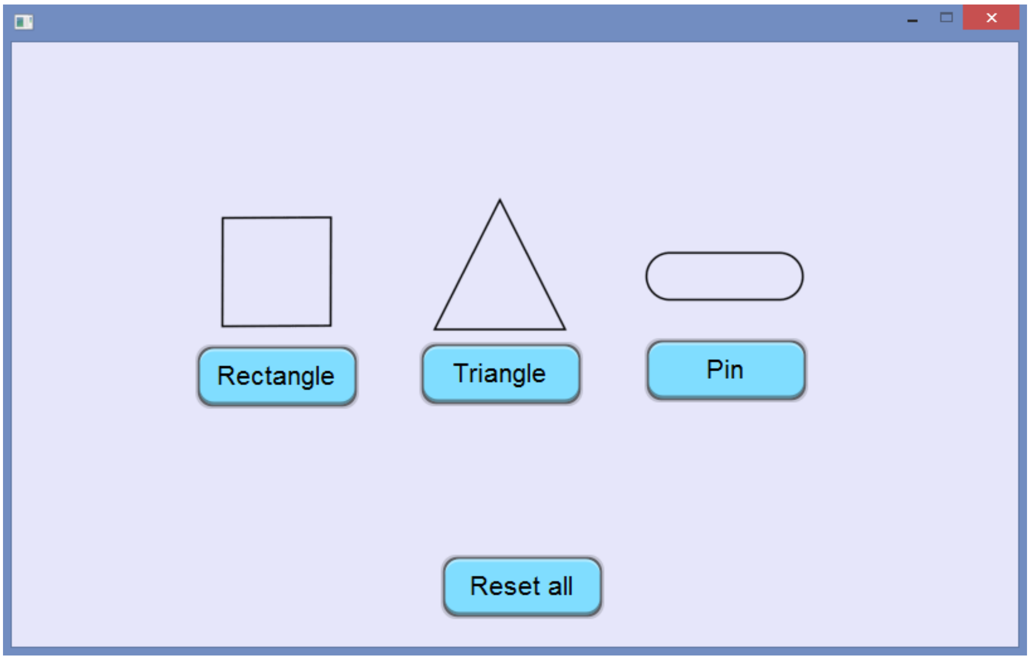


Figure II-22: operator choose the shape

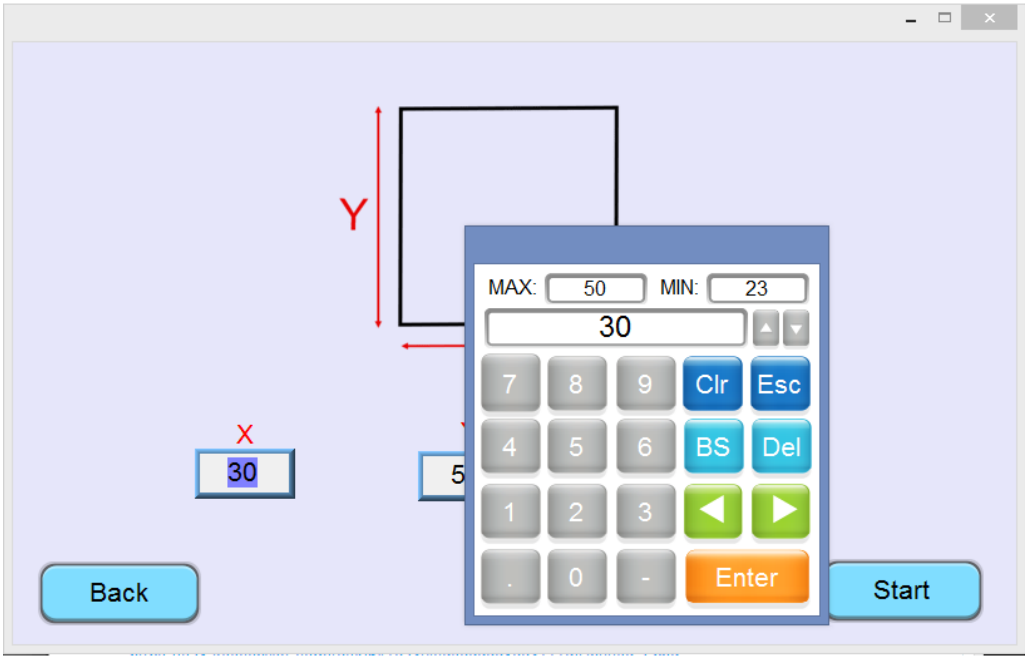


Figure II-23: operator insert dimensions

4) The feeding mechanism grips the rebar and feeds it into the bending mechanism according to the desired length.

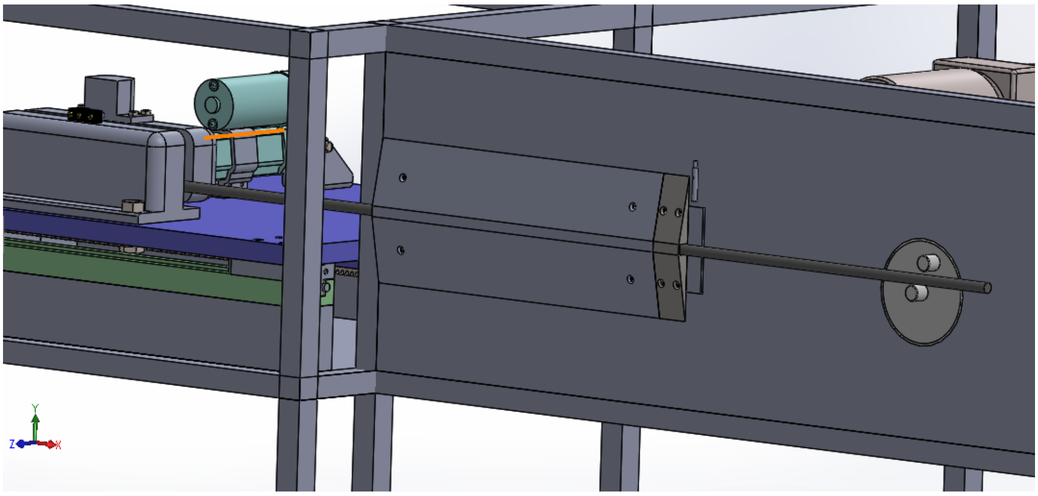


Figure II-24: feeding the rebar process

5) The bending mechanism bends the rebar at the desired angle, while the feeding mechanism returns to its original position.

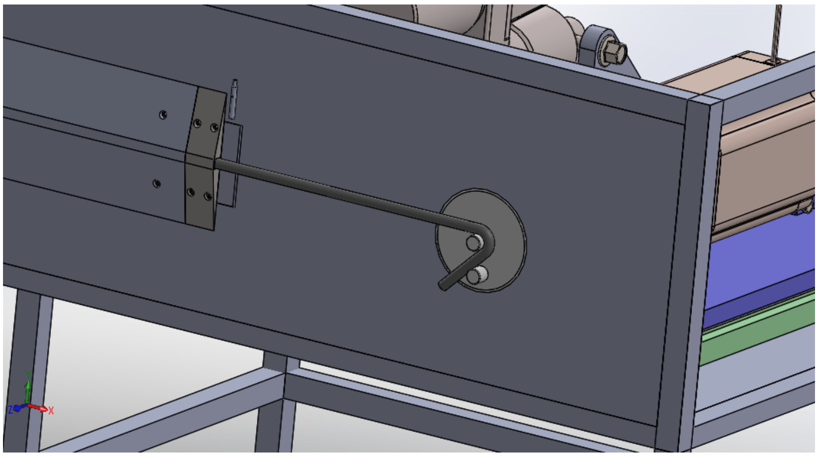


Figure II-25: bending the rebar process

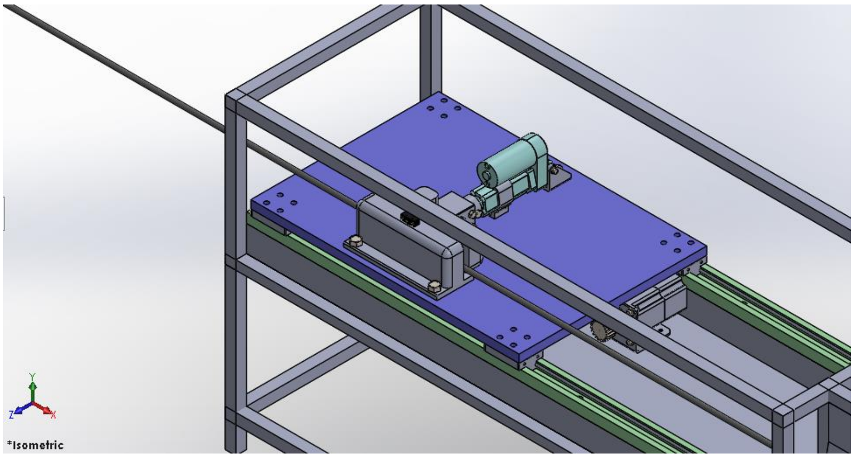


Figure II-26: stage is back to the initial position

6) Steps 4 and 5 are repeated until the final shape of the rebar is completed.

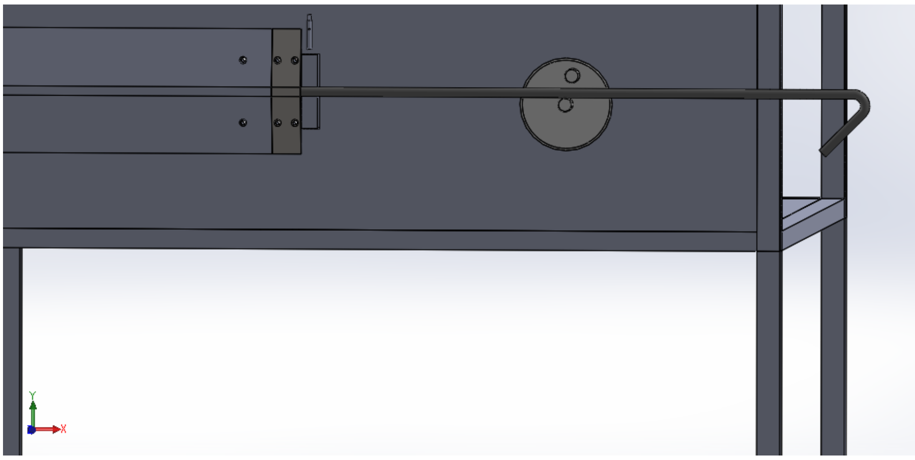


Figure II-27: feeding first length

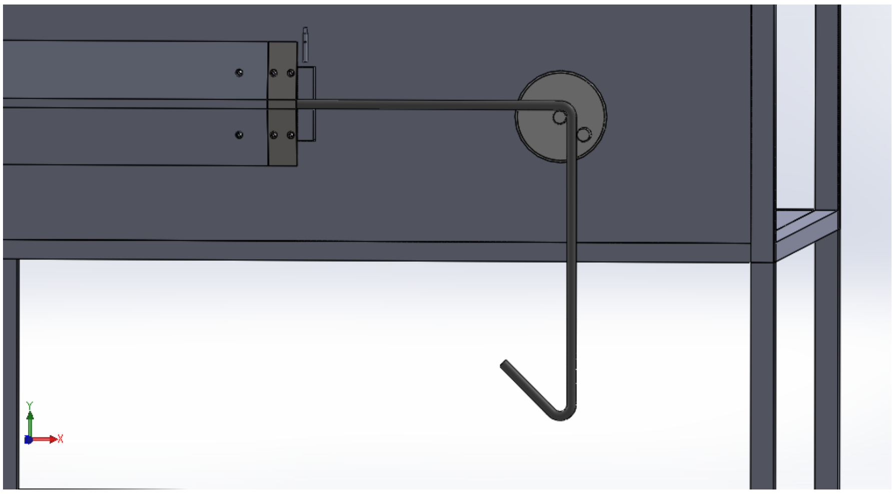


Figure II-28: bending first corner

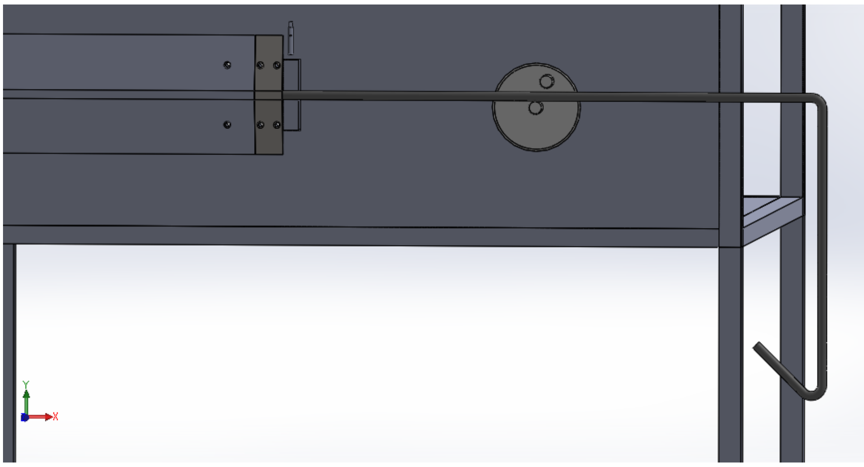


Figure II-29: feeding second length

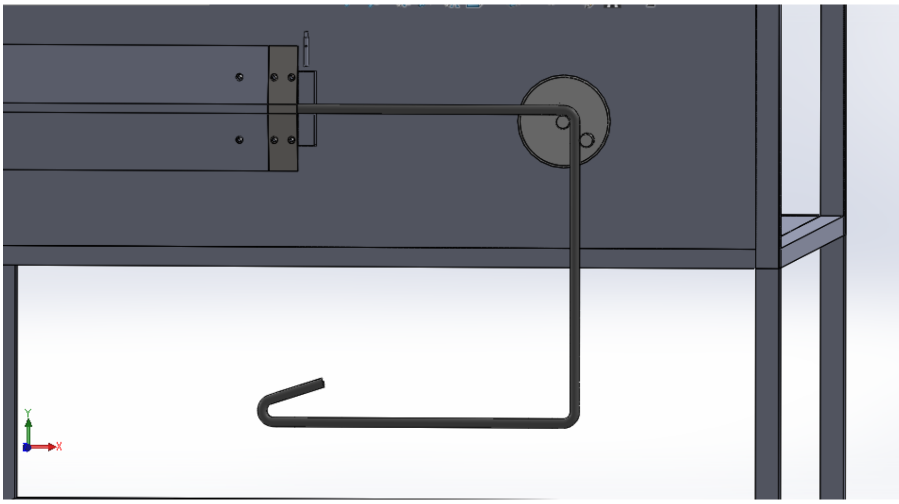


Figure II-30: bending second corner

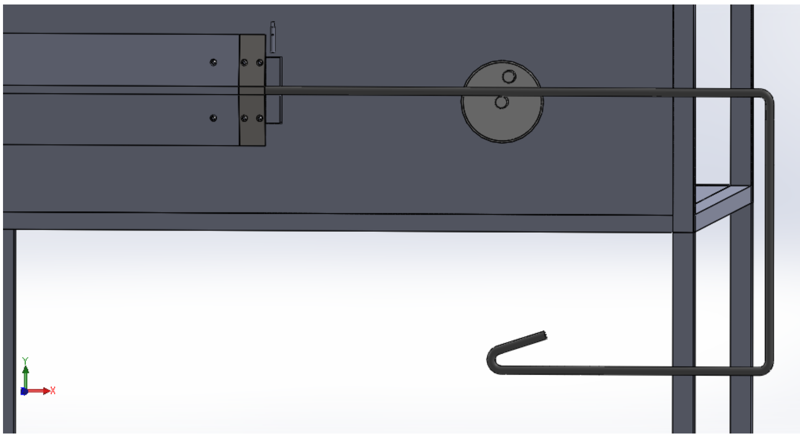


Figure II-31: feeding third length

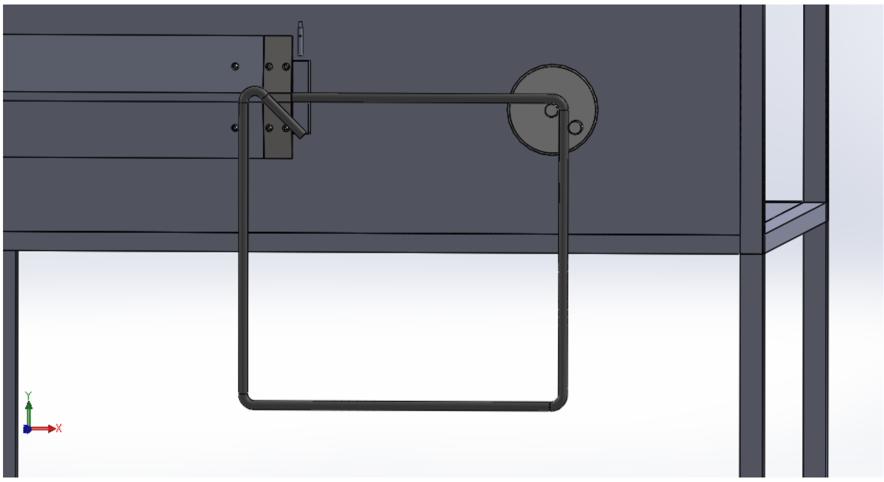


Figure II-32: bending third corner

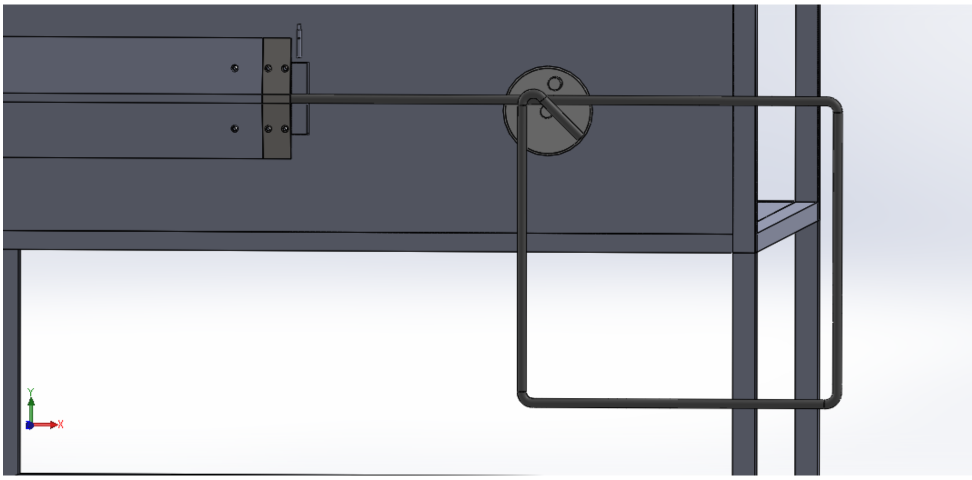


Figure II-33: feeding fourth corner

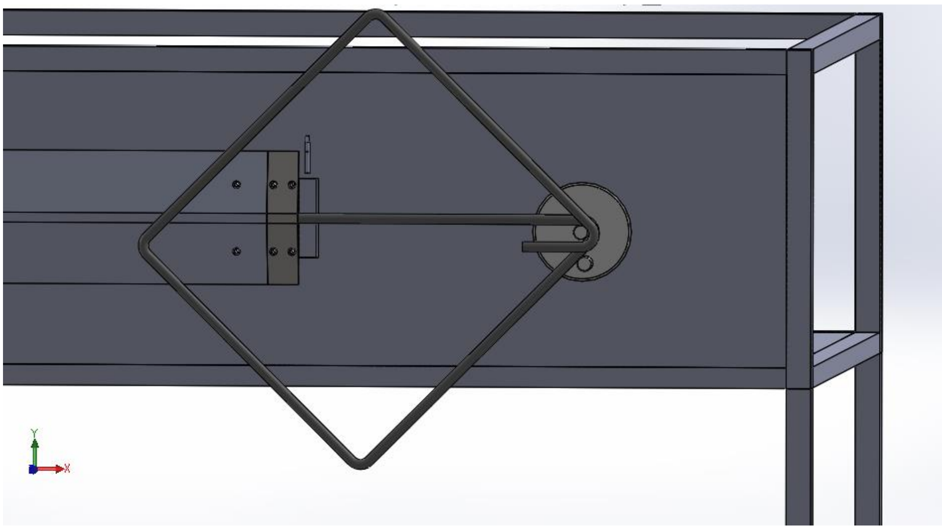


Figure II-34: bending fourth corner

7) The disc is pulled backward to allow the feeding mechanism to pull the rebar back by the necessary distance.

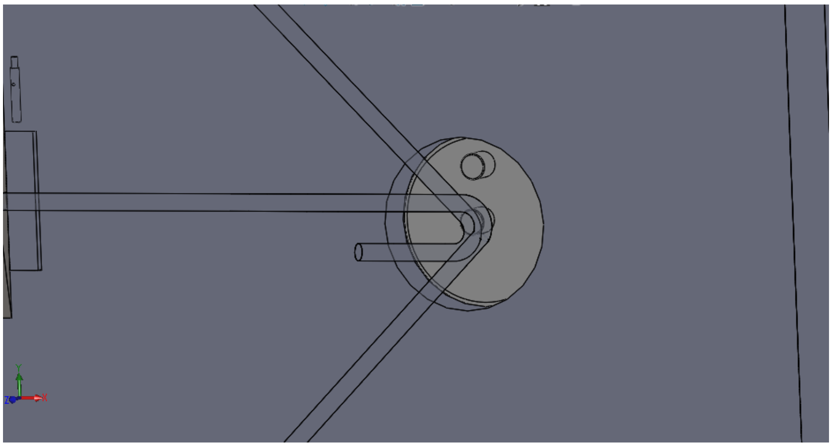


Figure II-35: disc pulled backward

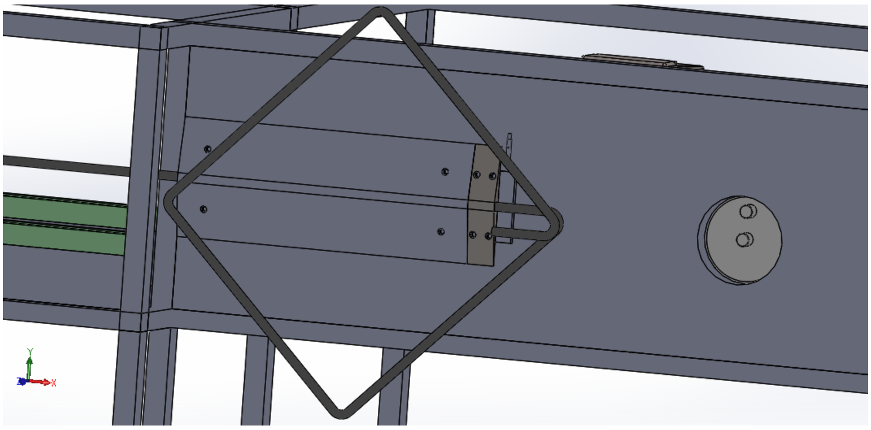


Figure II-36: rebar pulled back

8) In the final step, the linear actuator cuts the rebar.

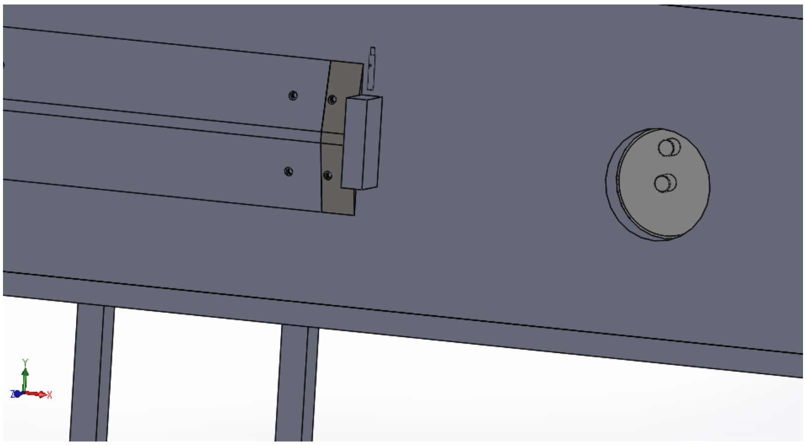


Figure II-37: cutting the rebar

9) These steps are repeated in a loop until the requested quantity of rebar is produced.

The final product will be as shown in the following image:

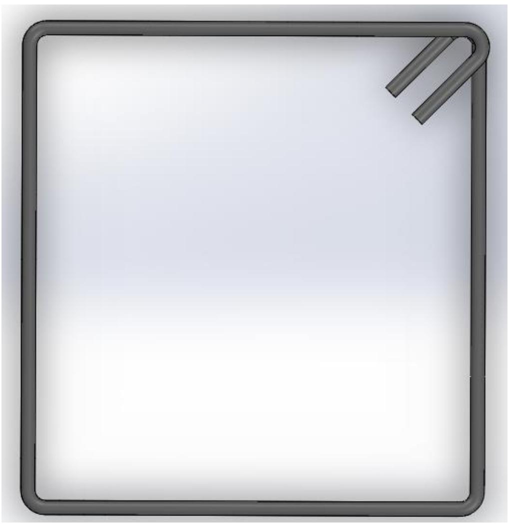


Figure II-38: final product

II.5 FUNCTIONAL DIMENSIONS

Although we have previously stated that our design is in its preliminary stages, there are some crucial dimensions that we simply cannot ignore. We will discuss them below.

1) The diameter of the first pin in disk dimensions must be 12 mm based on the diameter of the reinforcement bars in beams.

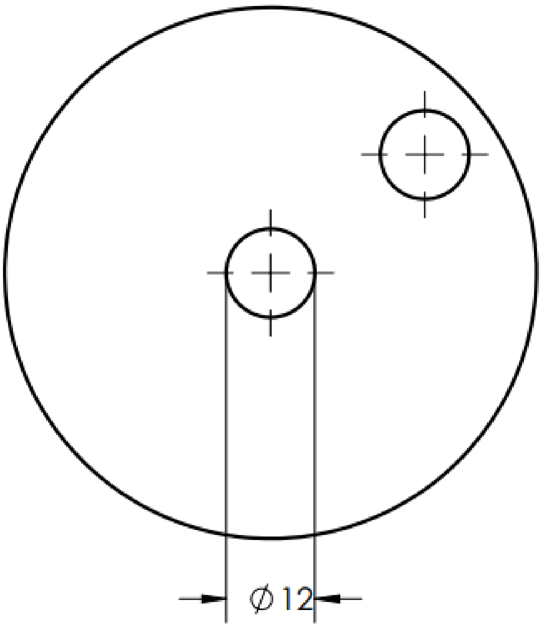


Figure II-39: pin diameter

2) The minimum distance between the two pins should be 20 mm

$$d_{p\,min} = 2R_{pin} + D_{rebar} \quad \text{(II.1)}$$

$$d_{p\,min} = 2 \times 6 + 8 = 20\,mm$$

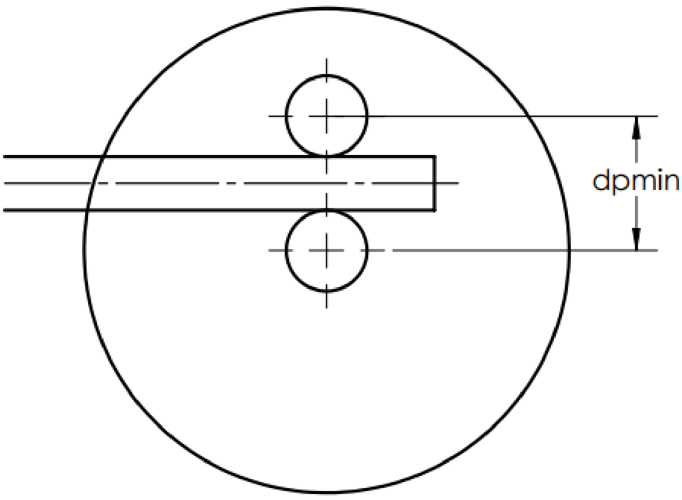


Figure II-40: minimum distance between the two pins

While the maximum distance should be 25.61 mm.

$$d_{p\,max} = \sqrt{(dx_{pins})^2 + (\mathrm{dy_{pins}})^2} \qquad (\mathrm{II.2})$$

$$d_{p\,max} = \sqrt{(L_{hook})^2 + (2R_{pin} + D_{rebar})^2} \qquad (\mathrm{II.3})$$

$$d_{p\,max} = \sqrt{(16)^2 + (12 + 8)^2} = 25.61 \text{ mm}$$

While L_{hook} is the minimum length of the hook.

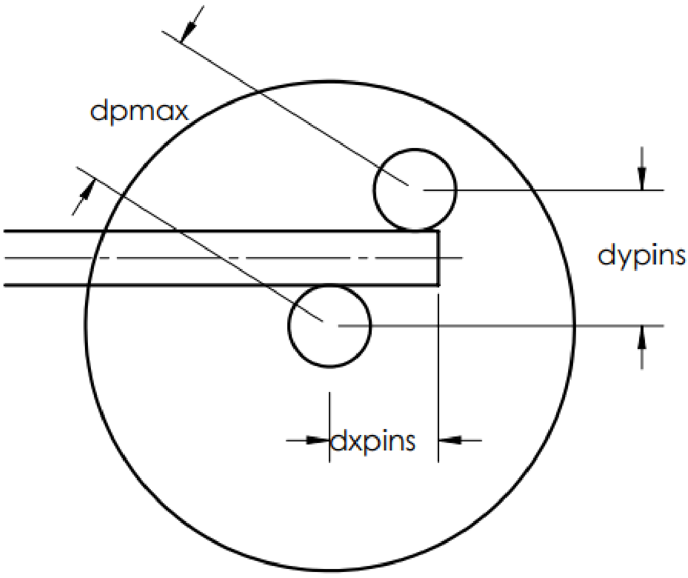


Figure II-41: maximum distance between the two pins

3 The height of the pins should be greater than or equal to the diameter of the rebar.

$$h_{pin} \geq 8mm \qquad (\mathrm{II.4})$$

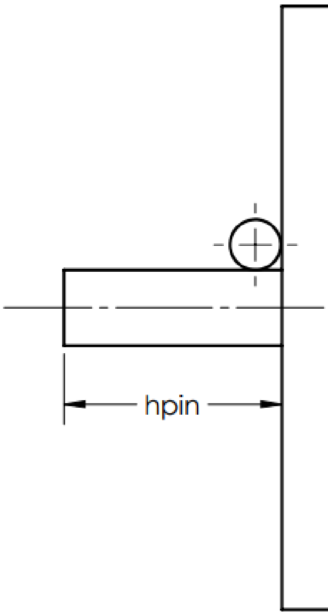


Figure II-42: height of the pins

4 The distance between the edge of the lifting part and the fixed pin should be less than or equal to the smallest side of the stirrups.

$$d_{LP} \leq 23mm \qquad (II.5)$$

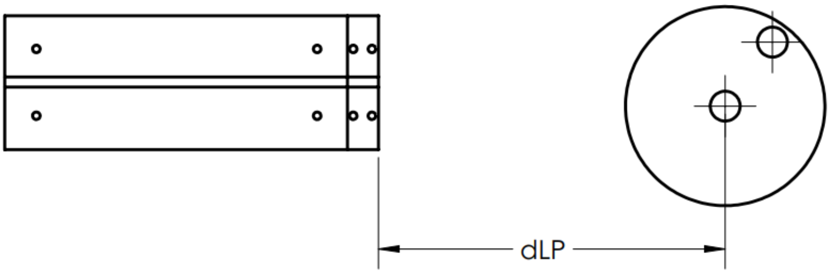


Figure II-43: distance between lifting part and the pin

5 The length of the lifting part should be:

$$L_L \geq L_{s\,max} - d_{LP} \qquad (II.6)$$

While:

$L_{s\,max}$: the longest side of the stirrup.

L_L: the length of the lifting part.

d_{LP}: the distance between the edge of the lifting part and the pin.

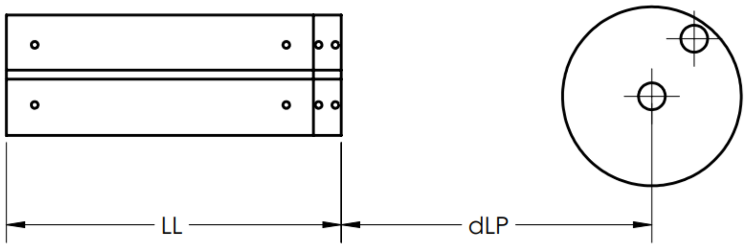


Figure II-44: length of the lifting part

5 The length of the stage in the feeding mechanism must be equal to the longest side of the stirrup to make the stage travel once for each side.

$$L_{stage} = 50cm \tag{II.7}$$

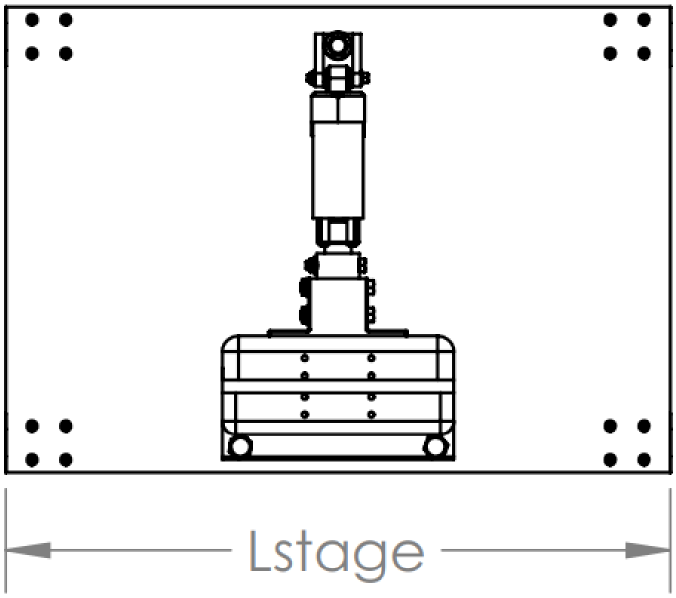


Figure II-45: length of the feeding stage

CHAPTER III MECHANICAL DESIGN

III.1 INTRODUCTION

III.2 BENDING MECHANISM

III.3 CUTTING MECHANISM

III.4 FEEDING MECHANISM

III.1 INTRODUCTION

Mechanical design is considered an embodiment stage for conceptual design. By relying on mechanical laws and concepts, the conceptual design can be translated from a 3D design stage to an idea that can be applied in reality.

III.2 BENDING MECHANISM

III.2.1 Required force to bend the rebar:

To calculate the force required to bend an 8-mm rebar, we need to calculate the strength condition of bending as follows:

$$\frac{dx_{pins} \times F_{bending} \times R_{rebar}}{I} > \sigma_y \quad \text{(III. 1)}$$

Where:

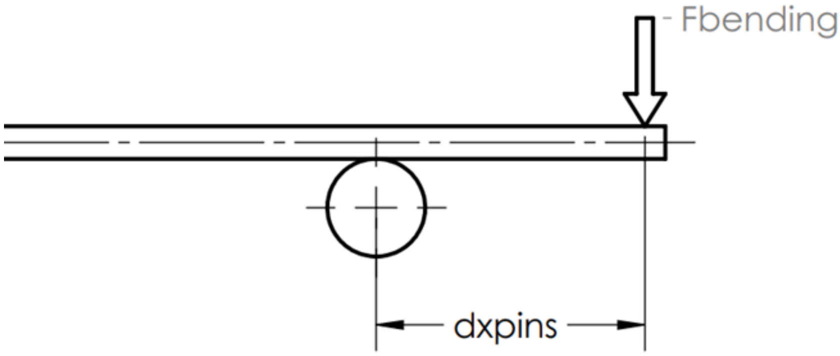
σ_y : yield strength of the rebar material (Pa)

$F_{bending}$: force required to bend the rebar (N)

R_{rebar}: radius of the rebar (m)

dx_{pins}: distance between the two pins along the x-axis (m)

I : moment of inertia of rebar (m^4)



$\sigma_y = 500 \times 106$ Pa , $R_{rebar} = 0.004$ m , $D_{rebar} = 0.008$ m $dx_{pins} = 0.016$ m

$$I = \frac{\pi \times D_{rebar}^4}{64} \quad \text{(III. 2)}$$

$$I = \frac{\pi \times 0.008^4}{64} = 2.01062 \times 10^{-10} m^4$$

$$F_{bending} > \frac{\sigma_y \times I}{dx_{pins} \times R_{rebar}} \quad \text{(III. 3)}$$

$$F_{bending} > \frac{500 \times 10^6 \times 2.01062 \times 10^{-10}}{0.016 \times 0.004}$$

$$F_{bending} > 1570.8\ N$$

So the required force should be 1570.8 N or higher, we took it as 1600 N.

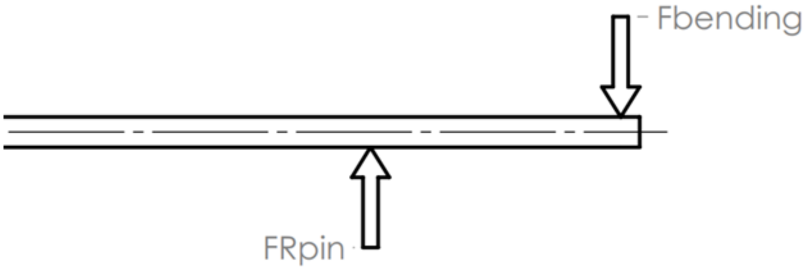
$$F_{bending} = 1600\ N$$

III.2.2 Bending disc material:

Using the equations of equilibrium, the resultant of the forces and moments equals zero as follows:

$$\sum Fext = F_{R\,pin} - F_{bending} = 0 \quad \text{(III. 4)}$$

$$F_{R\,pin} = F_{bending} \quad \text{(III. 5)}$$



After calculating the forces that are applied to the pins of the disc, we can choose the material of the disc and the pins based on shear and bending strength conditions.

- **Shear strength condition:**

$$\tau = \frac{F_{bending}}{A_{pin}} \qquad (III.6)$$

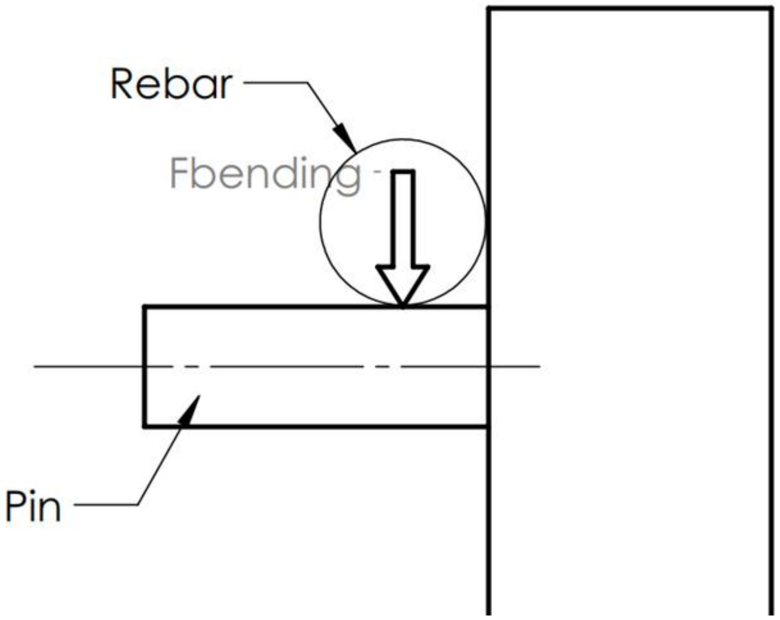
Where

τ : shear stress (N/m^2)

$F_{bending}$: applied force (N)

A_{pin} : cross-sectional area of the pin (m)

$F_{bending}$= 1600 N



$$A_{pin} = \pi \times D_{pin}^2 \qquad (III.7)$$

$$A_{pin} = \pi \times 0.012^2 = 4.5 * 10^{-4} m^2$$

$$\tau = \frac{1500}{4.5 * 10^{-4}} = 3.33 * 10^6 N/m^2 = 3.4\ Mpa$$

Shear Strength condition:

$$\sigma_{material} > 3.4\ Mpa$$

- **Bending strength condition:**

$$\sigma_b = \frac{M_{max}}{\frac{I}{R_{pin}}} \tag{III.8}$$

where:

σ_b : bending stress (Pa)

R_{pin} : radius of the pin (m)

I : moment of inertia of rebar (m^4)

M_{max} : maximum bending moment (N.m)

While :

$$M_{max} = R_{rebar} \times F_{bending} \tag{III.9}$$

M_{max} = 0.004 × 1500 = 6 N.m

$$I = \frac{\pi \times {D_{pin}}^4}{64} \tag{III.10}$$

$$I = \frac{\pi \times 0.012^4}{64} = 1.01 \times 10^{-9} m^4$$

R_{pin} = 0.006 mm , M_{max} = 6 N.m , I = $1.01 \times 10^{-9} m^4$

$$\sigma_b = \frac{6}{\frac{1.01\times10^{-9}}{0.006}} = 35643564.356 N/m^2 = 35.6 Mpa$$

bending Strength condition:

$$\sigma_{y\ material} > 35.6\ Mpa$$

The required material must have a yield strength greater than 35.6 MPa and a shear strength greater than 3.4 MPa; therefore, we will choose S355 non-alloy steel, which has the following properties:

Brinell Hardness	150	Elastic Modulus	190Gpa
Elongation at Break	20 %	Fatigue Strength	230Mpa
Impact Strength	31 J	Poisson's Ratio	0.29
ShearModulus	73GPa	ShearStrength	330MPa
UltimateStrength	530MPa	YieldStrength	330MPa

Table III-1: S355 proprieties

- Those calculations are applied to both pins since they have the same diameter.

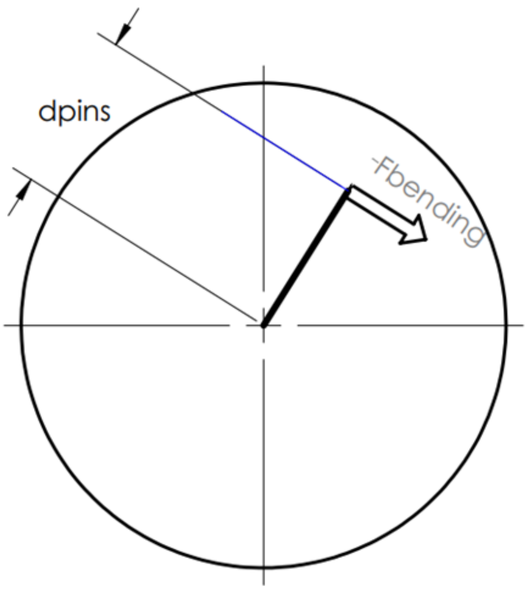
III.2.3 Required torque to bend the rebar:

$$T_{bending} = F_{bending} \times d_{pins} \qquad (III.11)$$

Where: $T_{bending}$ = bending torque (N.m)

$F_{bending}$ = bending force (N)

d_{pins} = length of arm (m)



$F_{bending}$ = 1600 (N), d_{pins} = 0.02561 (m)

$$T_{bending} = 1600 \times 0.02561 = 45.8\ N.m$$

In summary, after performing the necessary calculations in this part, the required input torque for our bending gearbox should be 45.8 Nm or higher with a rotating speed of 1 rps.

Required input

$$\begin{cases} T_{D\ input} = 45.8\ N.m \\ \omega_{D\ input} = 1\ rps \end{cases}$$

III.2.4 Bending motor and gearbox:

After conducting an internet search for a motor that meets our requirements, we have identified one with the following specifications:

Parameter	value
Type	Stepper motor
product code	42HS79-8004S
frame size	NEMA 42
holding torque	30 N.m
step angle	1.8°
Rated current	8 A
Shaft diametre	19
micro step	1600 setp/rev
Coil type	Bipolar
Voltage	220 VAC

Table III-2: bending motor data [30]

Figure III-1: bending motor [30]

This motor with the frame size nema 42 can be linked with a gearbox that suits it, and it has the following specifications:

Parameter	value
Type	Double Stage Planetary Gearhead
product code	S9142TMPAN015D-S
Maximum input speed	5000 rpm
Input Shaft diameter	24 mm
Continuous Output Torque	168 n.m

Table III-3 bending gearbox data [31]

Figure III-2: bending gearbox [31]

To get the input torque and speed of the gearbox, we will use the following formula:

$$i = \frac{T_{G\ input}}{T_{G\ output}} = \frac{\omega_{G\ output}}{\omega_{G\ input}} \qquad (III.12)$$

$$T_{G\ input} = i \times T_{G\ output} \qquad (III.13)$$

$$T_{G\ input} = \frac{1}{15} \times 42 = 2.8\ N.m$$

$$\omega_{G\ input} = \frac{\omega_{G\ output}}{i} \qquad (III.14)$$

$$\omega_{G\ input} = \frac{1}{\frac{1}{15}} = 15\ rps = 900\ rpm$$

The required input:

$$\begin{cases} T_{G\ input} = 2.8\ \mathrm{N.m} \\ \omega_{G\ input} = 900\ \mathrm{rpm} \end{cases}$$

Using the torque speed curve, we can get the output torque that our stepper motor can provide depending on the required input of the bending gearbox.

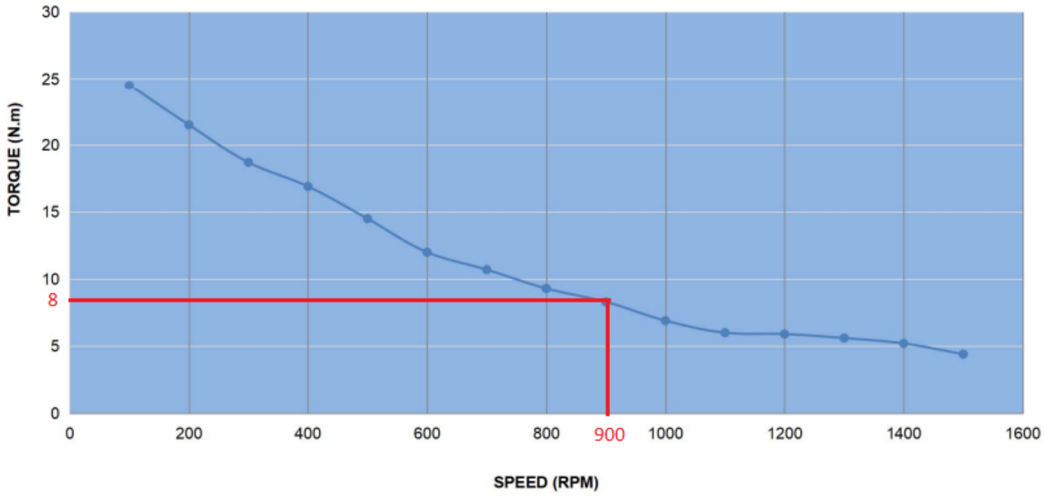


Figure III-3: bending motor torque speed curve [47]

III.2.5 Linear actuator in bending mechanism

The stage carries a mass of 20.7 kg.

$$\begin{cases} gearbox\ 7.9\ \text{kg} \\ \text{stepper motor}\ \ 11.7\ \text{kg} \\ \text{bending disc}\ 1.1\ \text{kg} \end{cases}$$

So we can calculate the required force to move the stage with the following formula:

$$F_{b\,stage} = \mu \times m_{b\,stage} \times g \qquad \text{(III. 15)}$$

Where:

$F_{b\ stage}$: required force to move the stage (N)

μ : coefficion of frection (μ = 0.01 approximately [48])

$m_{b\ stage}$: the mass (kg)

g: gravitational (m/s^2)

$m_{b\ stage}$ = 20.7 kg, g = 9.81 m/s^2, μ = 0.01

$$F_{b\,stage} = 0.01 \times 20.7 \times 9.81 = 2\ N$$

We chose a linear actuator with the following specifications:

Parameter	value
Type	Electric linear actuator
product code	S9142TMPAN015D-S
Input voltage	12 V
Max currant	5 A
Force	155 N
Stroke	25.4 mm
Speed	5 cm/s

Table III-4: electric linear actuator data [34]

Figure III-4: electric linear actuator [34]

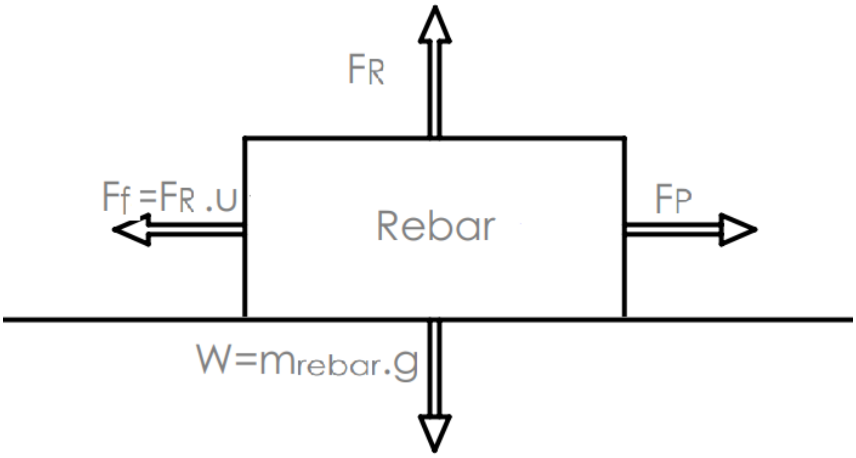
III.3 FEEDING MECHANISM

III.3.1 Required force in rack and pinion system:

- **Required force to pull the rebar**

In the following calculations, we will use the free body diagram for a better understanding of the forces acting on each part of our feeding mechanism. We will start with the required force to pull the rebar as follows:

While



F_R: reaction force(N)

F_f : fraction force(N)

F_P : Pulling force(N)

W : Weight (N)

In static equilibrium, the sum of the forces in each direction is equal to zero. This can be expressed mathematically as follows:

$$\sum Fx = 0 \quad \text{(III. 16)}$$

$$\sum Fy = 0 \quad \text{(III. 17)}$$

$$\sum Fx = F_p - f_f = 0 \quad \text{(III. 18)}$$

$$\sum Fy = \mathrm{F_R} - W = 0 \quad \text{(III. 19)}$$

From the previous equations we can get the following:

$$F_p = f_f \qquad (III.20)$$

$$\mathrm{F_R} = W \qquad (III.21)$$

By substituting the formulas of fraction and weight we can get the following

$$F_p = \mathrm{F_R} \,.u \qquad (III.22)$$

$$F_R = m_{rebar} \times g \qquad (III.23)$$

Therefore, we can get the following

$$F_p = m_{\,rebar} \times g \times u \qquad (III.24)$$

While:

m_{rebar} : rebar mass (kg)

μ : coffetion of frection

g = gravitational (10 m/s^2)

m_{rebar} = 4.8 kg, u = 1 , g = 10 m/s^2

$$F_p = 4.8 \times 10 \times 1 = 48\,N$$

So the required force to pull the rebar is 48 N

- **The required force to move the stage**

So we can calculate the required force to move the stage with the following formula:

$$F_{f\,stage} = \mu \times m_{f\,stage} \times g \qquad (III.25)$$

Where:

$F_{f\,stage}$: required force to move the stage (N)

μ : coefficion of frection (μ = 0.01 approximately [48])

$m_{f\,stage}$: the mass (m = 5 kg approximately) g : gravitational

$m_{f\ stage}$ = 5 kg , g = 10 m/s^2, μ = 0.01

$$F_{f\ stage} = 0.01 \times 5 \times 10 = 0.5\ N$$

That means the stage itself needs a force of 0.5 N to move.

After the previous calculations, we can get the force that our rack and pinion system should deliver, which is:

$$F = F_{f\ stage} + F_p \quad (III.26)$$

$$F = 48 + 0.5 = 48.5\ N$$

III.3.2 Rack and pinion Dimensions

To calculate gear and rack dimensions, we will use the following table, which summarizes all the equations:

Item	symbol	formula
Pitch Diameter	d	d = m x z
Outside Diameter	de	de = d + 2m
Root Diameter	df	df = d – 2.5m
Tooth depth	h	h = 2,25 x m
Circular Pitch	Pc	Pc = πx m
Tooth thickness	B	B=10 . m

Table III-5: spur gear equations [35]

Assumptions:

- We will choose m as 1.5 from row I of table x based on the recommendation of the **JIS** standard

I	II
0.1	0.15
0.2	0.25
0.3	0.35
0.4	0.45
0.5	0.55
0.6	0.7
	0.75
0.8	0.9
1	1.125
1.25	1.375
1.5	1.75
2	2.25
2.5	2.75

I	II
3	3.5
4	4.5
5	5.5
6	(6.5)
	7
8	9
10	11
12	14
16	18
20	22
25	28
32	36
40	45
50	

Table III-6: standard values of module [36]

- We will choose Z = 20 since this number of teeth is mathematically the optimum in terms of tangential force and system backlash. [37]
- We will choose that α = 20 degrees since it is suitable for most gear applications. [38]

- **Calculations :**

$$d = m \times z \quad \text{(III.27)}$$

$$d = 1.5 \times 20 = 30\, mm$$

$$h = 2.25 \times m \quad \text{(III.28)}$$

$$h = 2.25 \times 1.5 = 3.375\, mm$$

$$de = d + 2 \times m \quad \text{(III.29)}$$

$$de = 30 + 2 \times 1.5 = 33 mm$$

$$df = d - 2.5 \times m \quad \text{(III.30)}$$

$$df = 30 - 2.5 \times 1.5 = 26.25 mm$$

$$Pc = \pi \times m \quad \text{(III.31)}$$

$$Pc = \pi \times 1.5 = 4.72 mm$$

$$B = 10 \times m \qquad (III.32)$$

$$B = 10 \times 1.5 = 15mm$$

All results can be summarized in the following table:

Proprieties	pinion	rack
m	1.5	
d	30	
Z	20	
De	33	
df	26.25	
pc	4.72	
h	3.375	
B	15	
L		500
α	20	

Table III-7: rack and pinion proprieties

III.3.3 Rack and pinion material

Using Lewis equation for spur gear, we can calculate the bending stress as follows:

$$\sigma = Kv \frac{Ft}{B * m * y} \qquad (III.33)$$

While:

σ : Bending stress(pa)

Kv : velocity factor (m/s)

F_t: tangential force(N)

y: Lewis form factor

B: Tooth thickness(m)

m: module (m)

First we will calculate velocity factor using the following formula:

$$Kv = \frac{6.1 + v}{6.1} \quad (III.34)$$

While:

v : pitch line velocity(m/s)

$$Kv = \frac{6.1 + 1}{6.1} = 1.16 m/s$$

Now we will calculate the bending stress as follows

Kv = 1.16 m/s, F_t = 48.5 N, y = 0.32, m = 0.0015 m, B = 0.015 m

$$\sigma = 1.16 * \frac{48.5}{0.015 * 0.0015 * 0.32} = 7813888.8 \text{ Pa} = 7.8 \text{ MPa}$$

So we need a material that has a yield strength of 7.8 MPa or higher.

We will choose AISI 4615 [54], which has the following properties:

Brinell Hardness	150	Elastic Modulus	190 GPa
Elongation at Break	27 %	Fatigue Strength	260 MPa
Poisson's Ratio	0.29	YieldStrength	350 MPa
ShearModulus	73 GPa	ShearStrength	310 MPa
UltimateStrength	480 MPa		

Table III-8: AISI 4615 properties

III.3.4 Feeding Motor :

First we need to calculate the torque and speed of the motor

$$P_{motor} = P_{rack\ and\ pinion} \tag{III.35}$$

$$T_m\ \omega_m = F_{rack} \times V_{rack} \tag{III.36}$$

We have:

$$P_{motor} = T_m \times \omega_m \tag{III.37}$$

$$P_{rack\ and\ pinion} = F_{rack} \times V_{rack} \tag{III.38}$$

$$T_m = R_{pinion} \times F_{rack} \tag{III.39}$$

While :

T_m : the torque(N.m)

ω_m : angular speed (rad/s)

F_{rack}: the linear force (N)

V_{rack} : linear speed (m/s)

R_{pinion} : pinion radius(m)

By substituting (III.39) in (III.36) we will find:

$$R_{pinion} \times F_{rack} \times \omega_m = F_{rack} \times V_{rack} \tag{III.40}$$

$$\omega_m = \frac{V_{rack}}{R_{pinion}} \tag{III.41}$$

$$\omega_m = \frac{1}{0.015} = 66.7\ \frac{rad}{s} = 10.61\ rps$$

$$T_m = R_{pinion} \times F_{rack} \tag{III.42}$$

$$T_m = 0.015 \times 48.5 = 0.72\ N.m$$

After conducting an internet search for a motor that meets our requirements, we have identified one with the following specifications:

Parameter	value
Type	Steper motor
product code	AM23HS84B0-BR01
frame size	NEMA23(56mm)
holding torque	1.5 N.m
step angle	1.8°
Rated current.	3.7 A
Shaft diametre	8
micro step	20000setp/rev
Coil type	Bipolar
Voltage	48 V

Table III-9: feeding motor data [40]

Figure III-5: feeding motor [40]

Using the torque speed curve, we can get the output torque that our stepper motor can provide depending on the required input speed of the rack and pinion system.

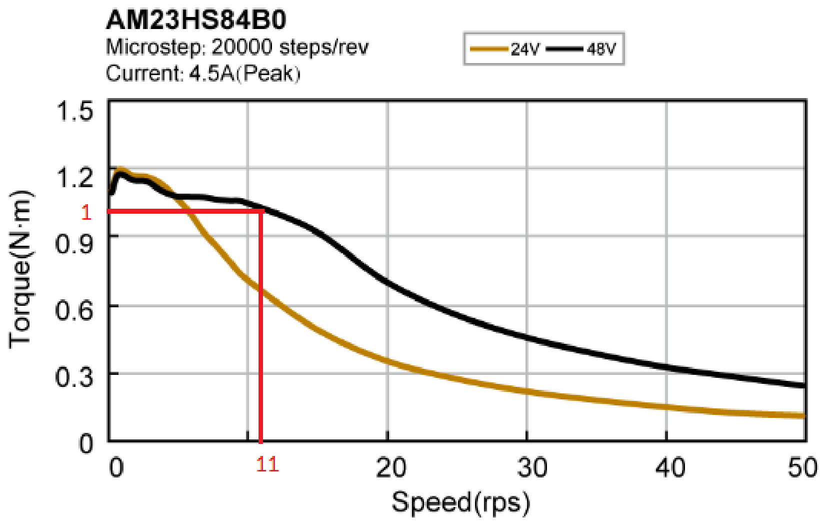


Figure III-6: feeding motor torque speed curve [40]

III.4 CUTTING MECHANISM:

III.4.1 Required force to cut the rebar

To calculate the required force for cutting an 8-mm rebar made of E500 steel, we can use the following formula:

$$\tau = \frac{F_{cutting}}{A_{rebar}} \quad \text{(III. 43)}$$

Where

$F_{cutting}$: the cutting force (N)

A_{rebar} : the cross-sectional area of the rebar (m^2)

τ : the shear stress required to cut the rebar (Pa)

$$A_{rebar} = \pi \times {R_{rebar}}^2 \quad \text{(III. 44)}$$

$$A_{rebar} = \pi \times 0.004^2 = 5.03 \times 10^{-5}$$

We could not find any information's about shear stress or ultimate tensile strength of fe E500 so we will assume that it has the same value of minimum tensile strength

σ_{tp} = 550 Mpa

$$\tau = \sigma_{tp} \times 0.5$$

[41]#(III. 45)

$$\tau = 550 \times 0.5 = 275 \times 10^6 \text{ Pa}$$

$$F_{cutting} = \tau \times A_{rebar} \quad \text{(III. 46)}$$

$$F_{cutting} = 275 \times 10^6 \times 5.03 \times 10^{-5} = 1.383 \times 10^4 \text{ N}$$

Required input

$$\{ \text{F}_{\text{cutting}} = 1.383 \times 10^4 \text{ N or higher}$$

III.4.2 Cutting actuator:

After conducting an internet search for a linear actuator that meets our requirements, we have identified one with the following specifications:

Parameter	value
Type	Electro-hydraulic linear actuator
Product code	REH50
Stroke	50 mm
Dynamic Force	25000 N
Speed	6 mm/s
Power	300 w
Input voltage	48 VDC

Table III-10: cutting linear actuator data [42]

Figure III-7: cutting linear actuator [42]

CHAPTER IV ELECTRICAL DESIGN

IV.1 INTRODUCTION

IV.2 STEPPER MOTOR

IV.3 STEPPER DRIVER

IV.4 ELECTRIC LINEAR ACTUATOR

IV.5 ELECTROHYDROLIC LINEAR ACTUATOR

IV.6 WIRING DIAGRAM

IV.1 INTODUCTION

One of the main parts of our machine project is the electrical design, in which we can include the used electrical parts with their specifications and the wiring diagram, which is necessary for understanding and troubleshooting the electrical circuit of our machine.

IV.2 STEPPER MOTOR

The motors utilized in our project are stepper motors, offering us the capability to control their speed and rotation degree. The specific motor we have identified for our needs has the following electrical specifications:

Parameter	Feeding motor	Bending motor
Coil type	Bipolar	Bipolar
Rated current	5.6 A	8 A
Voltage	48 V	220 V
AC/DC	DC	DC

Table IV-1: motors electrical data

IV.3 STEPPER DRIVER

To control the movement of our stepper motor, we need a stepper driver that suits it in many factors, such as voltage, control mode, etc. For both bending and feeding motors, we chose stepper drivers that had been recommended by the online stores that sell the stepper motors. The stepper drivers have the following details:

Parameter	Bending motor driver	Feeding motor driver
phase	2	2
Supply Voltage	180 – 240 VAC	24-75 VDC

Control Modes	Pulse Mode	Pulse Mode
Output Current	0.5 – 8.2 A	2.4 - 7.8 A
Encoder Feedback	No	NO
Step resolution	Full step (1.8°) – 125× micro stepping	Full step (1.8°) – 128×micro stepping
Step pulse frequency	Up to 200 kHz	Up to 2MHz

Table IV-2: drivers electrical data

IV.4 ELECTRIC LINEAR ACTUATOR

All the electric linear actuators that were used in our project are the same, and they have the following electrical specifications:

Parameter	Value
voltage	12 v
Max currant	5A

Table IV-3: electric linear actuator data

IV.5 ELECTROHYDROLIC LINEAR ACTUATOR

The electrohydraulic linear actuator that was used in our project has the following electrical specifications:

Parameter	Value
voltage	48 V
Max currant	6A

Table IV-4: electrohydraulic linear actuator data

IV.6 WIRING DIAGRAM

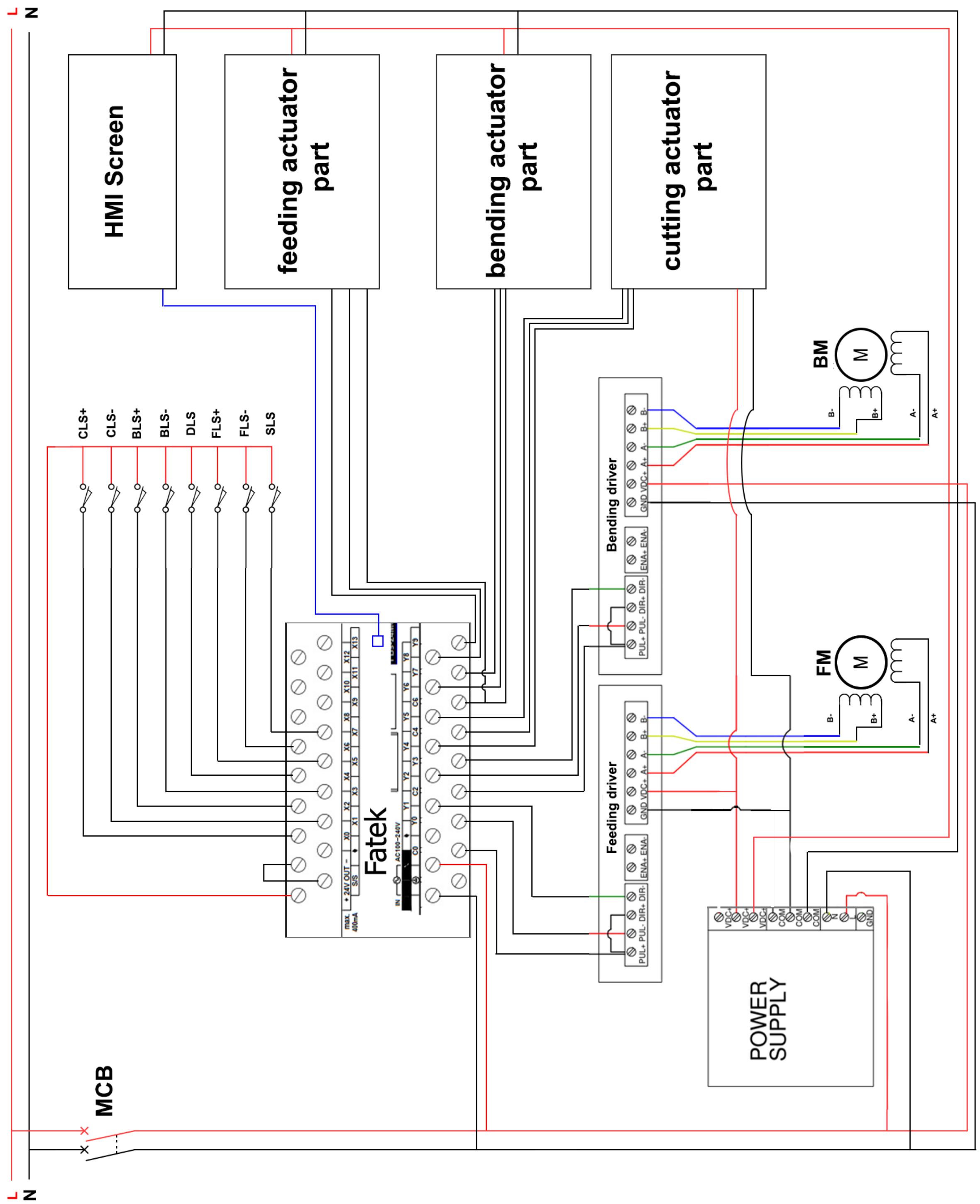


Figure IV-1: wiring diagram main structure

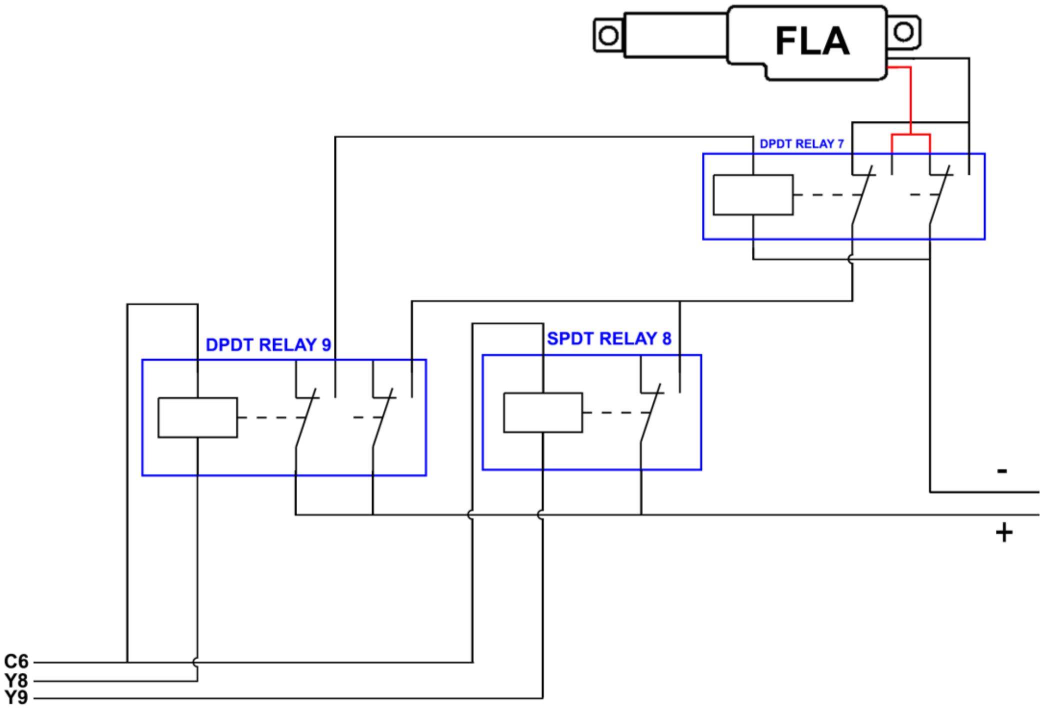


Figure IV-2: feeding actuator part

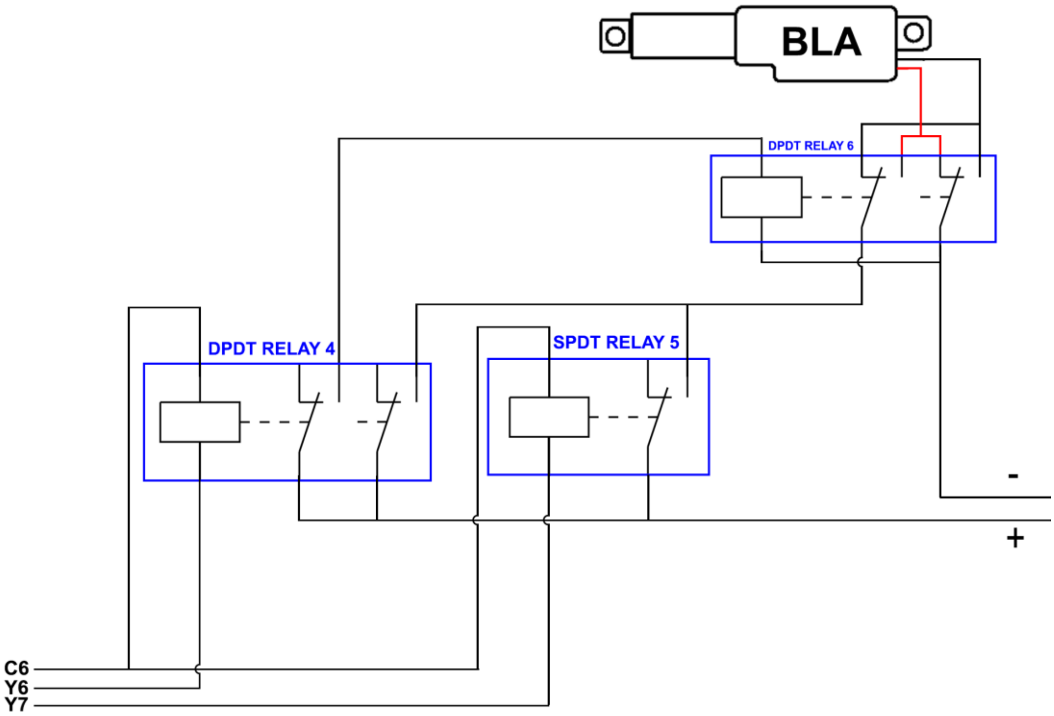


Figure IV-3: bending actuator part

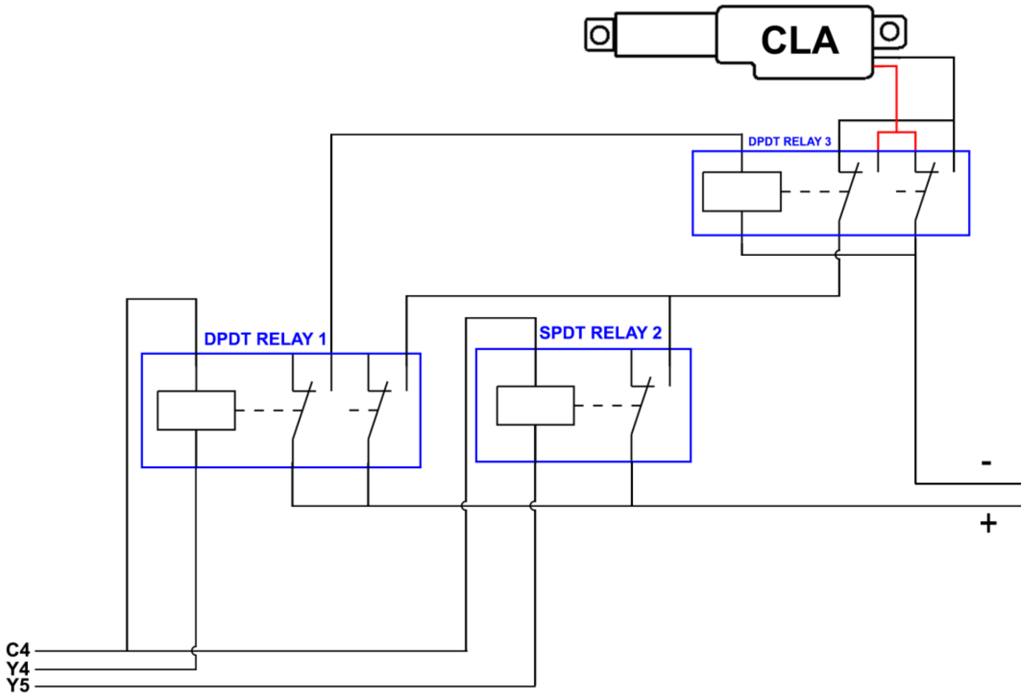


Figure IV-4: cutting actuator part

CHAPTER V PLC PROGRAMMING

V.1 INTRODUCTION

V.2 PLC NUMERIC INPUTS

V.3 HMI SCREEN

V.4 LADDER CODE

V.1 INTRODUCTION

In our research, we used an automated controller (PLC) to perform the machine mechanisms consistently and with minimal human intervention. The machine is programmed in ladder language with the help of a software called winproladder, while the HMI screen is programmed with a software called easybuider pro. In addition to the programming, we did some necessary calculations to link user inputs and the automatic controller.

V.2 PLC NUMERIC INPUTS

V.2.1 Feeding mechanism

Given:

- Input range on the HMI screen: 23 cm to 50 cm
- Increment on the HMI screen: 0.1 cm
- Speed of the rack: V_{rack} = 1 m/s = 1000 mm/s
- Speed of the motor: ω_m = 11 rps

First, we need to calculate how many revolutions the motor needs to rotate for the rack to move forward by 1 mm.

$$\omega_{1mm} = \frac{\omega_m}{V_{rack}} \quad (V.1)$$

$$\omega\_1mm = \frac{11}{1000} = 0.011\ rps$$

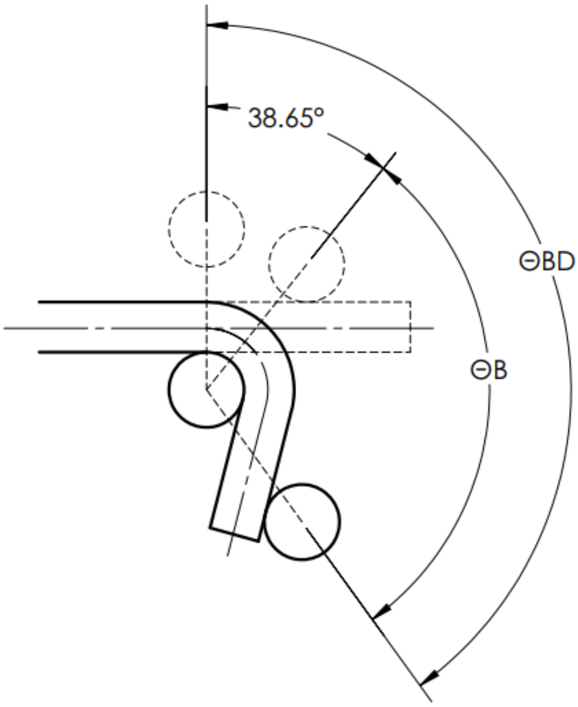
Now we need to calculate the number of steps for the rack to move 1mm .

$$S_{1mm} = \omega_{1mm} \times S_{fm} \quad (V.2)$$

$$S_{1mm} = 0.011 \times 20000 = 220\ step$$

While S_{fm} is microsteps of the feeding motor.

V.2.2 Bending mechanism



To get the bending angles of the disc we can use the following formula:

$$\theta_{BD} = 38.65 + \theta_B \quad (V.3)$$

While:

θ_{BD} is the bending angle of the disc

θ_B is the bending degree of the rebar

The bending motor has a frequency of 1600 microsteps per revolution, and based on the ratio of the gearbox, we can get how many steps we need for one revolution of the gearbox as follows:

$$\mu_{1\ revolution} = \frac{\mu_{motor}}{i} \quad (V.4)$$

$$= 1600 \times 15 = 24000\ step\ par\ revolution$$

While μ_{motor} is the frequency of the motor

So to convert the degrees to steps in PLC, we need to use the following formula:

$$microsteps = \frac{\theta_{BD} \times \mu_{1\,revolution}}{360} \quad (V.5)$$

While θ_{BD} is the bending angle of the disc

$\mu_{1\ revolution}$ is number of microsteps for one revolution

V.3 LOGIC ALLOCATION INPUT AND OUTPUTS

The following table present the inputs of logic allocation for the PLC

input	symbol	address	description
Bending limit swtich +	BLS+	X2	BLS+=0 when the bending linear actuator is extended
Bending limit swtich -	BLS-	X3	BLS-=1 when the bending linear actuator is retracted
Feeding limit swtich+	FLS+	X5	FLS+=1 when the feeding mechanism linear actuator is extended
Feeding limit swtich-	FLS-	X6	FLS-=1 when the feeding mechanism linear actuator is extended
Cutting limit swtich +	CLS+	X0	CLS+=1 when the cutting linear actuator is extended
Cutting limit swtich -	CLS-	X1	CLS-=0 when the cutting linear actuator is extended
Disc limit swtich	DLS	X4	DLS=1 The bending disc in potision 0 degree
Stage limit switch	SLS	X7	SLS=1 The stage is in the initial position

Table V-1:PLC inputs

The following table present the outputs of logic allocation for the PLC

output	symbol	address	Description
Bending motor pulses	BMP	Y2	Control the bending motor pulses
Bending motor direction	BMD	Y3	Control the bending motor direction
Feeding motor pulses	FMP	Y0	Control the feeding motor pulses
feeding motor direction	FMD	Y1	Control the feeding motor direction
Bending linear actuator +	BLA+	Y6	BLA+ Is to Extend the bending linear actuator
Bending linear actuator -	BLA-	Y7	BLA- Is to Retract the bending linear actuator
feeding linear actuator +	FLA+	Y8	FLA+ Is to Extend the feeding mechanism linear actuator
feeding linear actuator -	FLA-	Y9	FLA- Is to Retract the feeding mechanism linear actuator
cutting linear actuator +	CLA+	Y4	CLA+ Is to Extend the cutting linear actuator
cutting linear actuator -	CLA-	Y5	CLA- Is to Retract the cutting linear actuator

Table V-2: PLC outputs

The following table present the inputs and outputs of logic allocation for the HMI screen

Input/output	symbol	address	Description
Set rectangle	SETR	M0	Choose rectangle shape
Start rectangle	STARTR	M3	Start shaping rectangle shape
Set triangle	SETT	M100	Choose triangle shape
Start triangle	STARTT	M103	Start shaping triangle shape
Set pin	SETP	M200	Choose pin shape
Start pin	STARTP	M203	Start shaping pin shape
Reset all	RESETALL	M7	Reset motors and linear actuators to their initial position
counter	COUNTER	R54	A counter to show how many stirrups are shaped
HMI quantity	HMIQ	R55	The required quantity need to be shaped
HMI x	HMIX	R100	The length x
HMI y	HMIY	R101	The length y
First page	FIRSTP	M33	M33=1 back to the first screen

Table V-3: HMI inputs and outputs

V.4 HMI SCREEN

- The first screen is designed to let the user choose between varying shapes, including rectangle, triangle, and pin shape. Each shape leads to another screen under the same name, in addition to a reset button to reset everything in emergency situations.

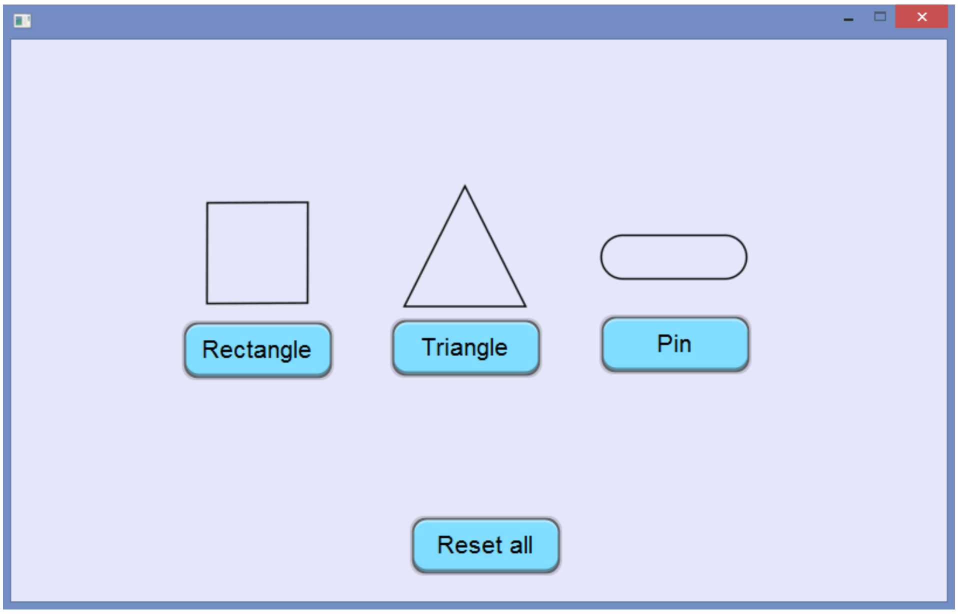


Figure V-1: home screen

- Each screen has input functions that allow the user to insert the required dimensions and quantity.

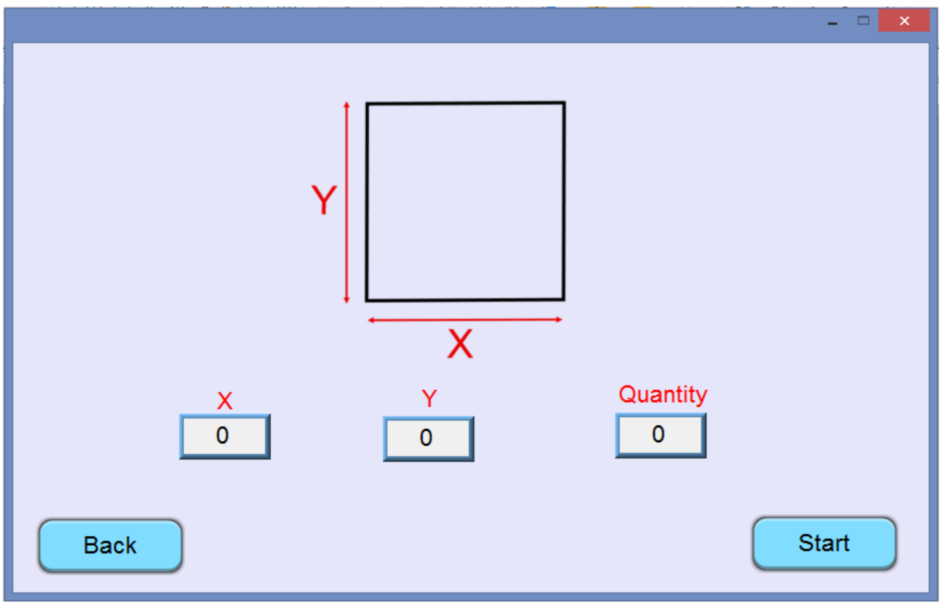


Figure V-2: rectangle screen

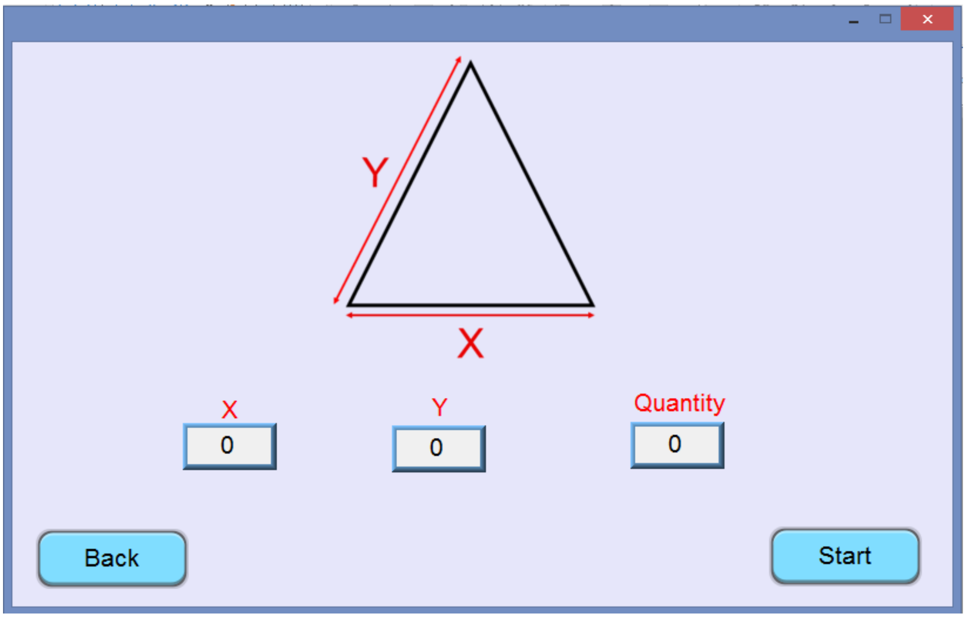


Figure V-3: triangle screen

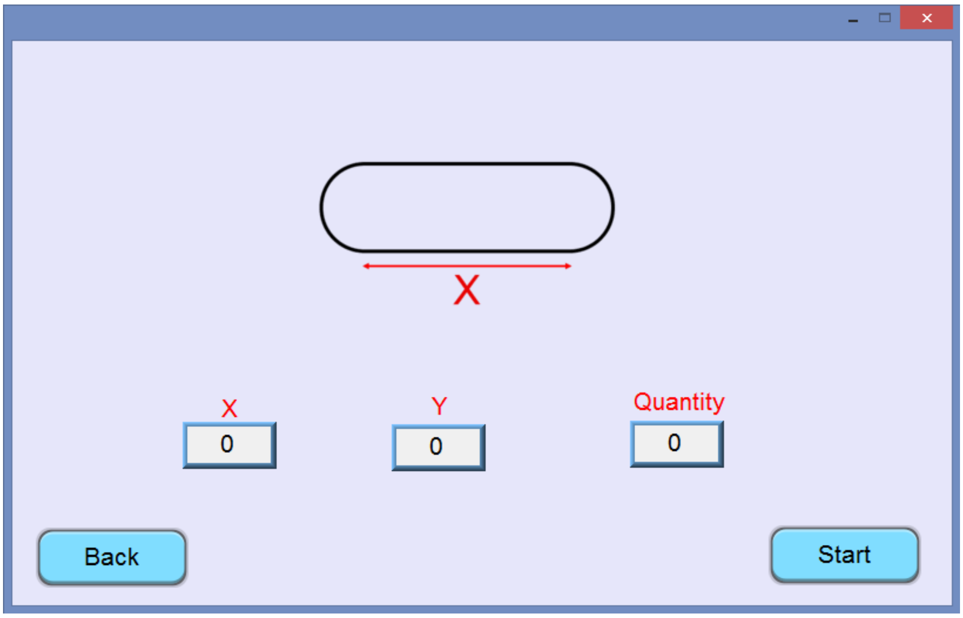


Figure V-4:pin screen

- After clicking on Start, a screen appears that shows the user how many stirrups have been shaped so far (Figure V.10). When the required quantity is fulfilled, the home screen (Figure V.6) will appear again.

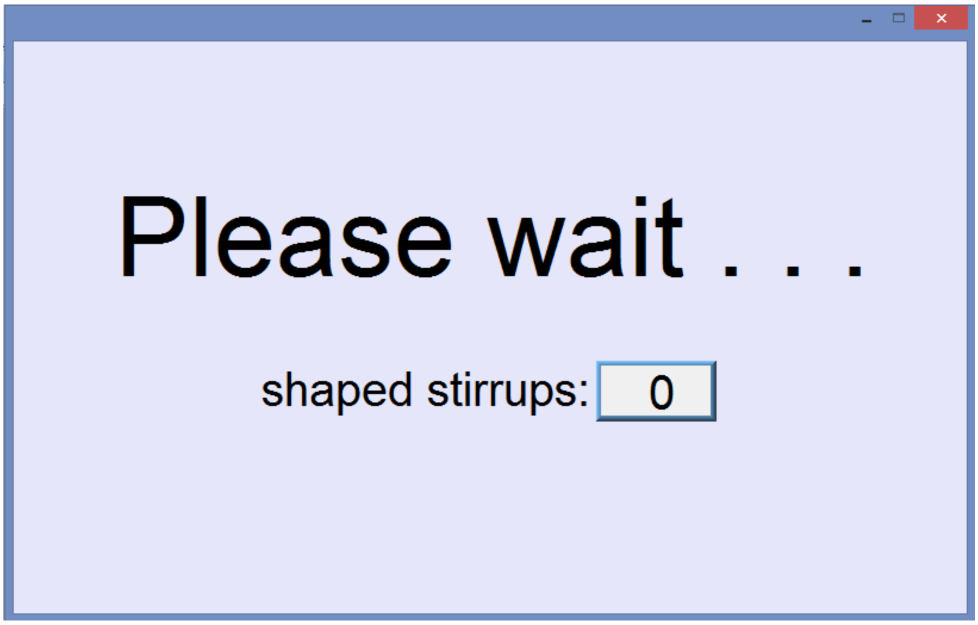


Figure V-5: waiting screen

V.5 LADDER CODE

Appendix A

GENERAL CONCLUSION

This research involved the study and preliminary design of a machine for shaping stirrups, where various aspects of the machine were highlighted, including feeding, bending, and cutting reinforcement bars, with the ability to control the quantity, dimensions, and shape of the stirrups that the machine can produce.

In addition to that, users can shape additional stirrup shapes by editing the programming code of the automation controller. This is due to the use of a stepper motor, which is capable of rotating in both directions with highly precise steps, offering flexibility for machine development.

Moreover, it is worth mentioning that most of the components used in the machine are cheap and available, or alternatives can be found in the Algerian market.

In summary, we can say that with proper investments, the machine is applicable on the ground. However, it is worth mentioning that it would be beneficial to do further research in the future to improve the speed of shaping stirrups.

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Appendix A

Ladder code

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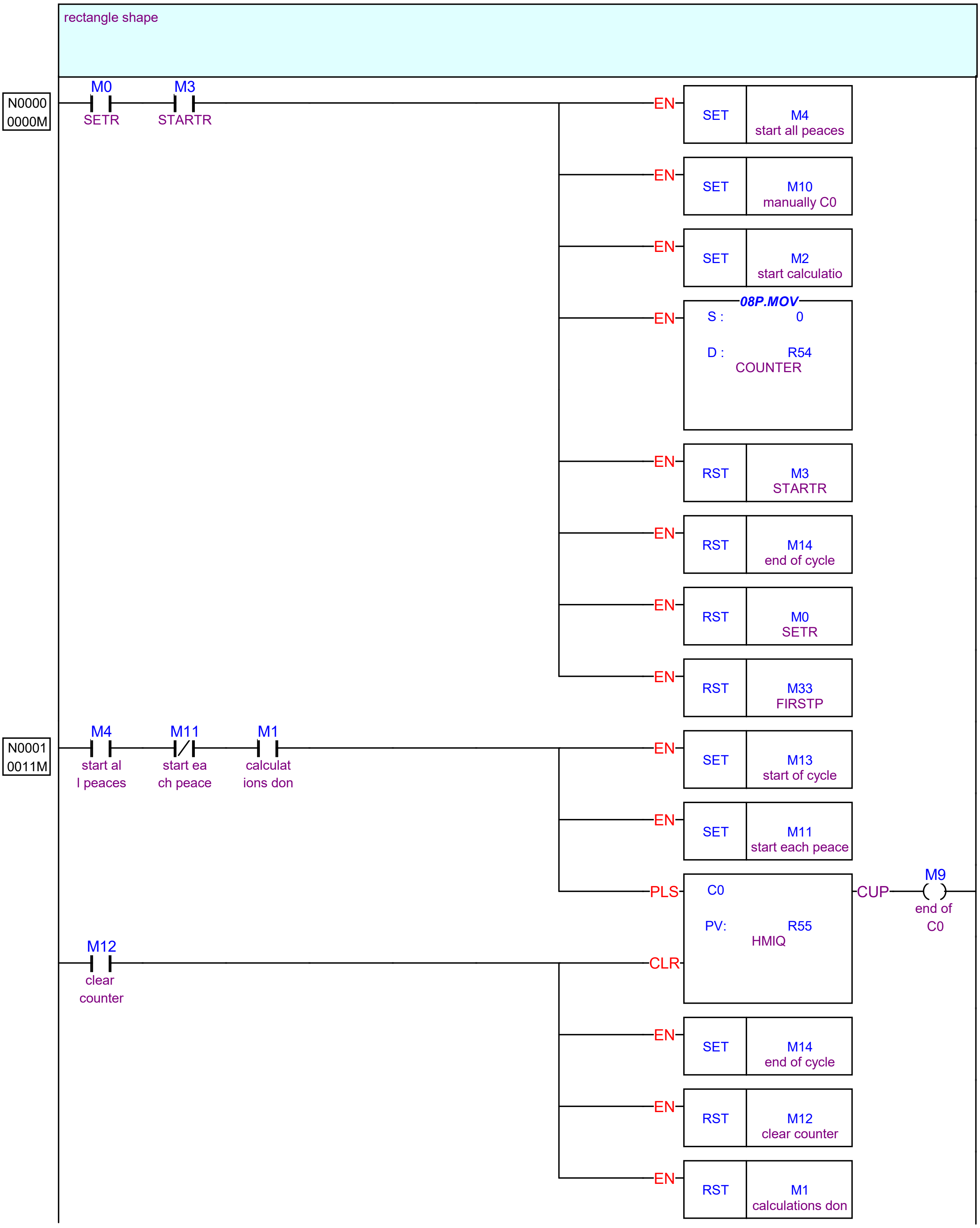

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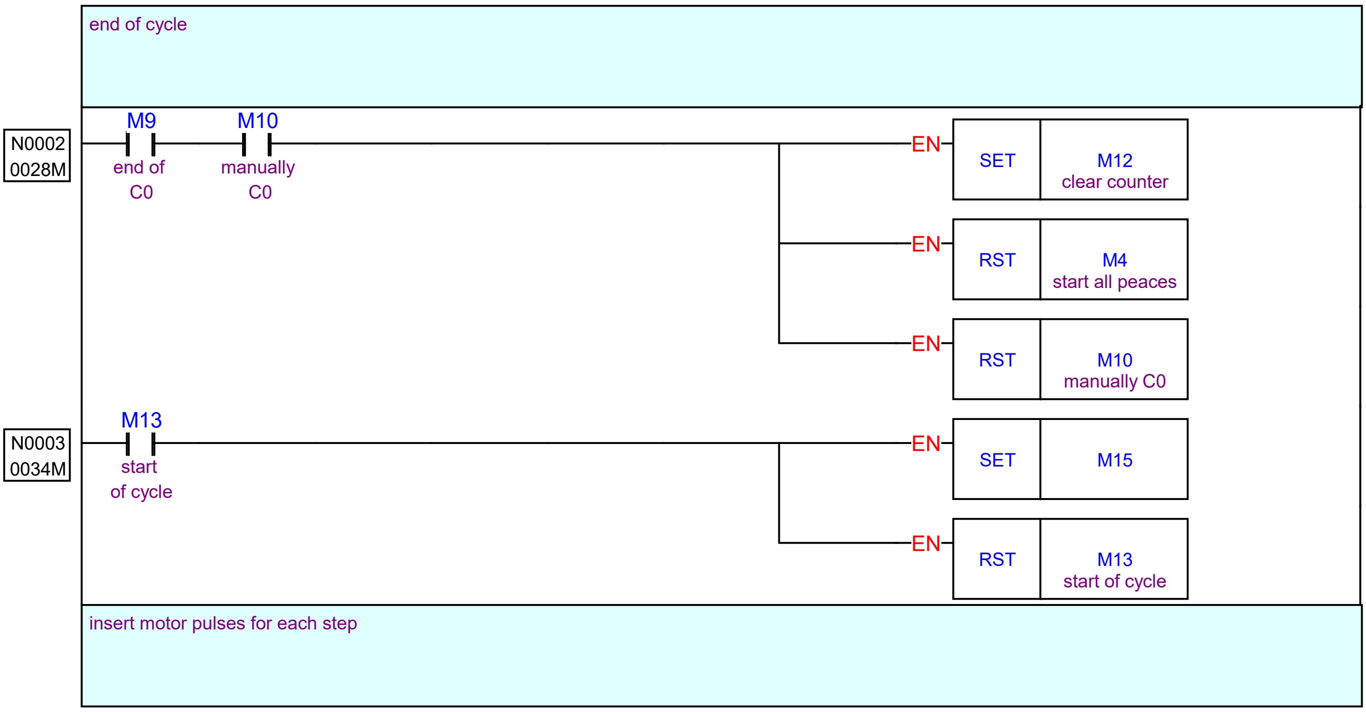

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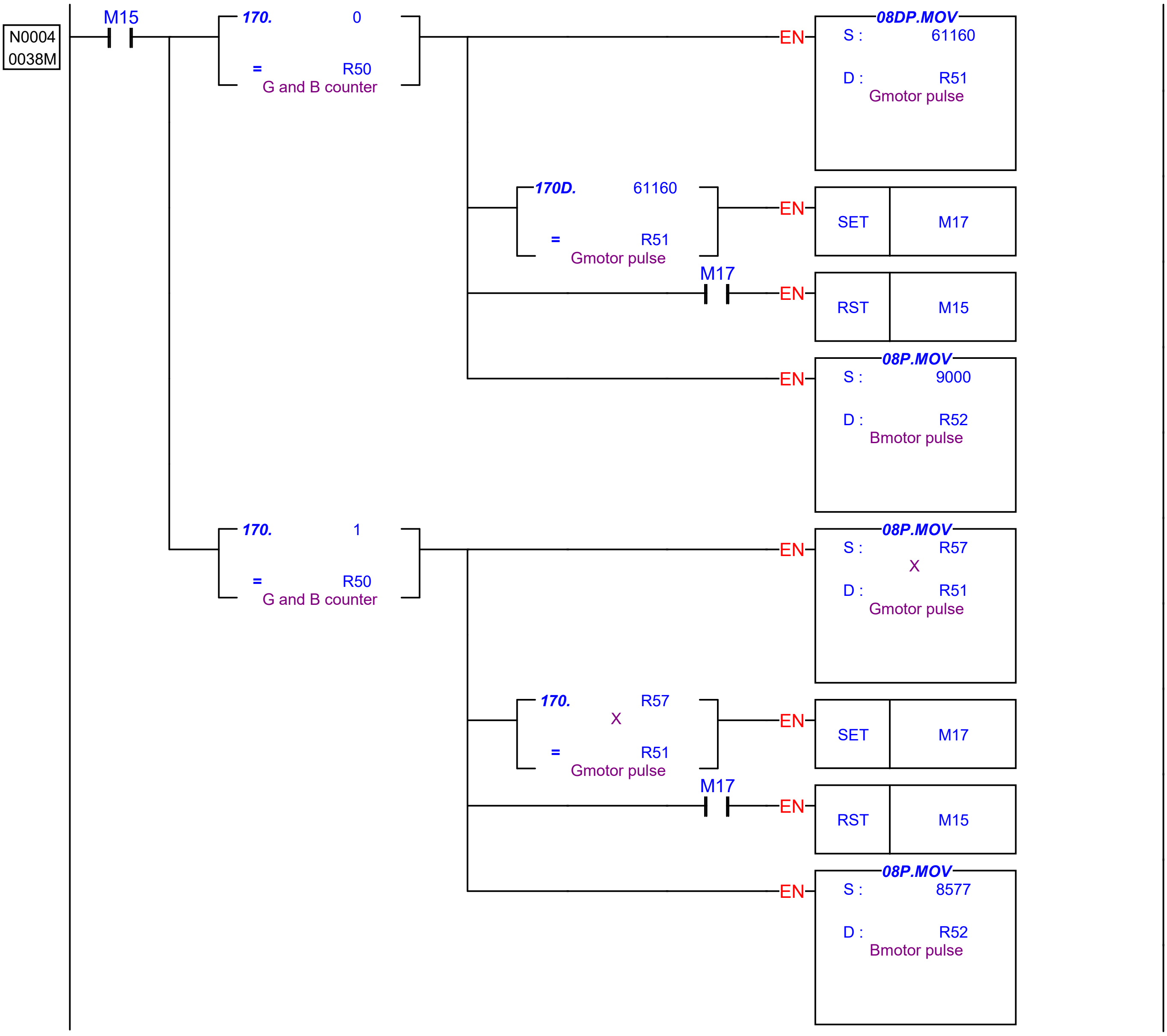

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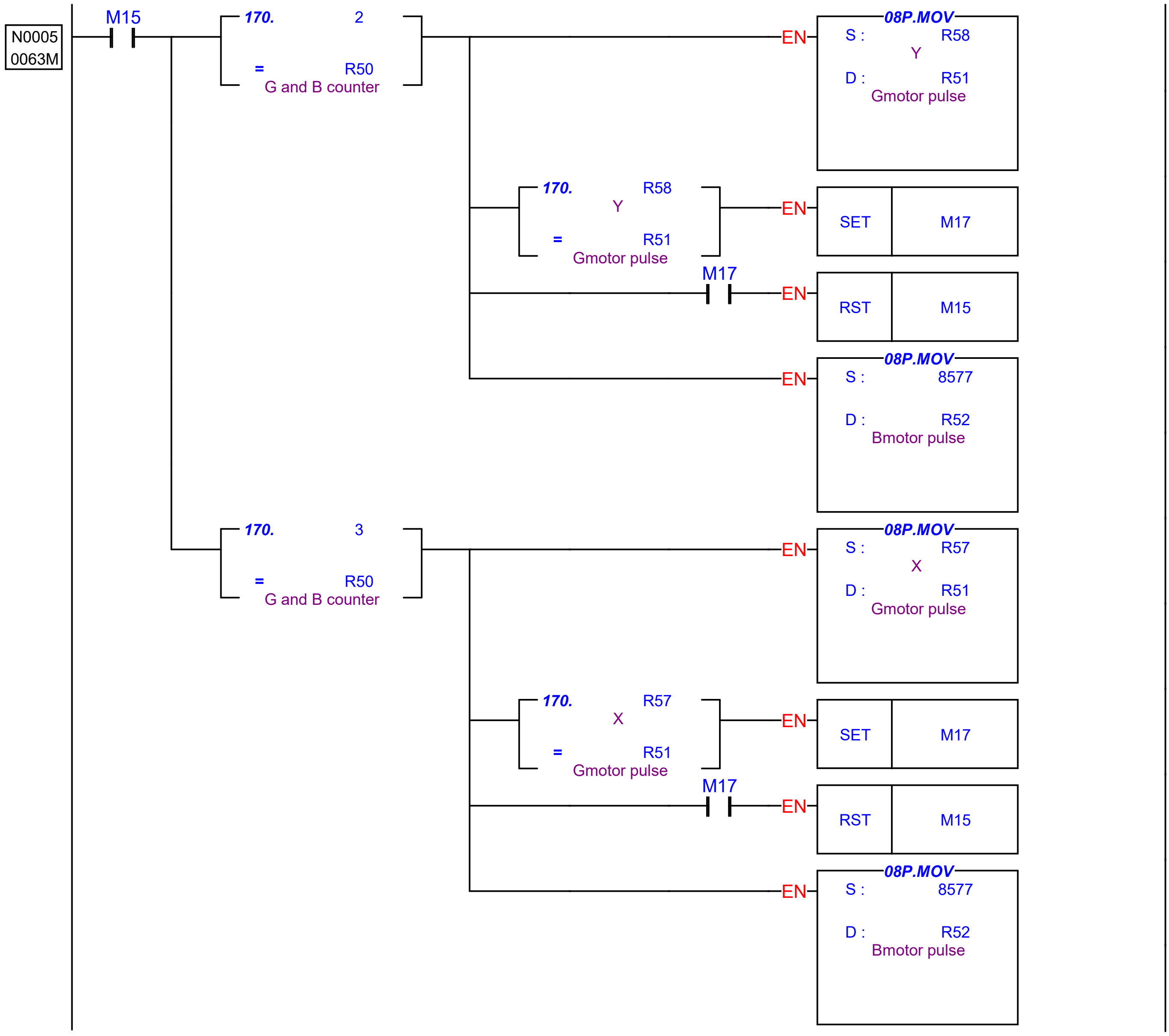

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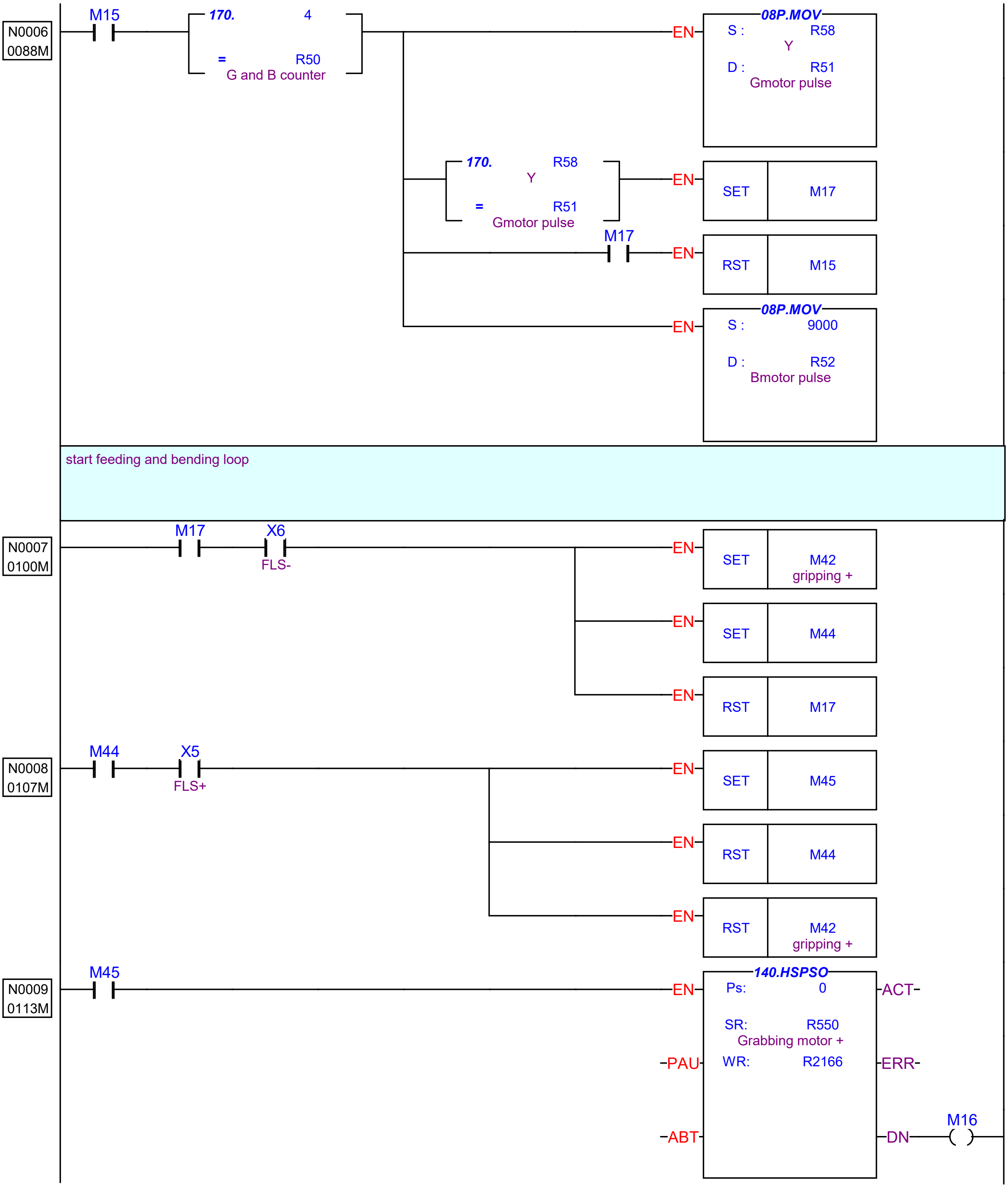

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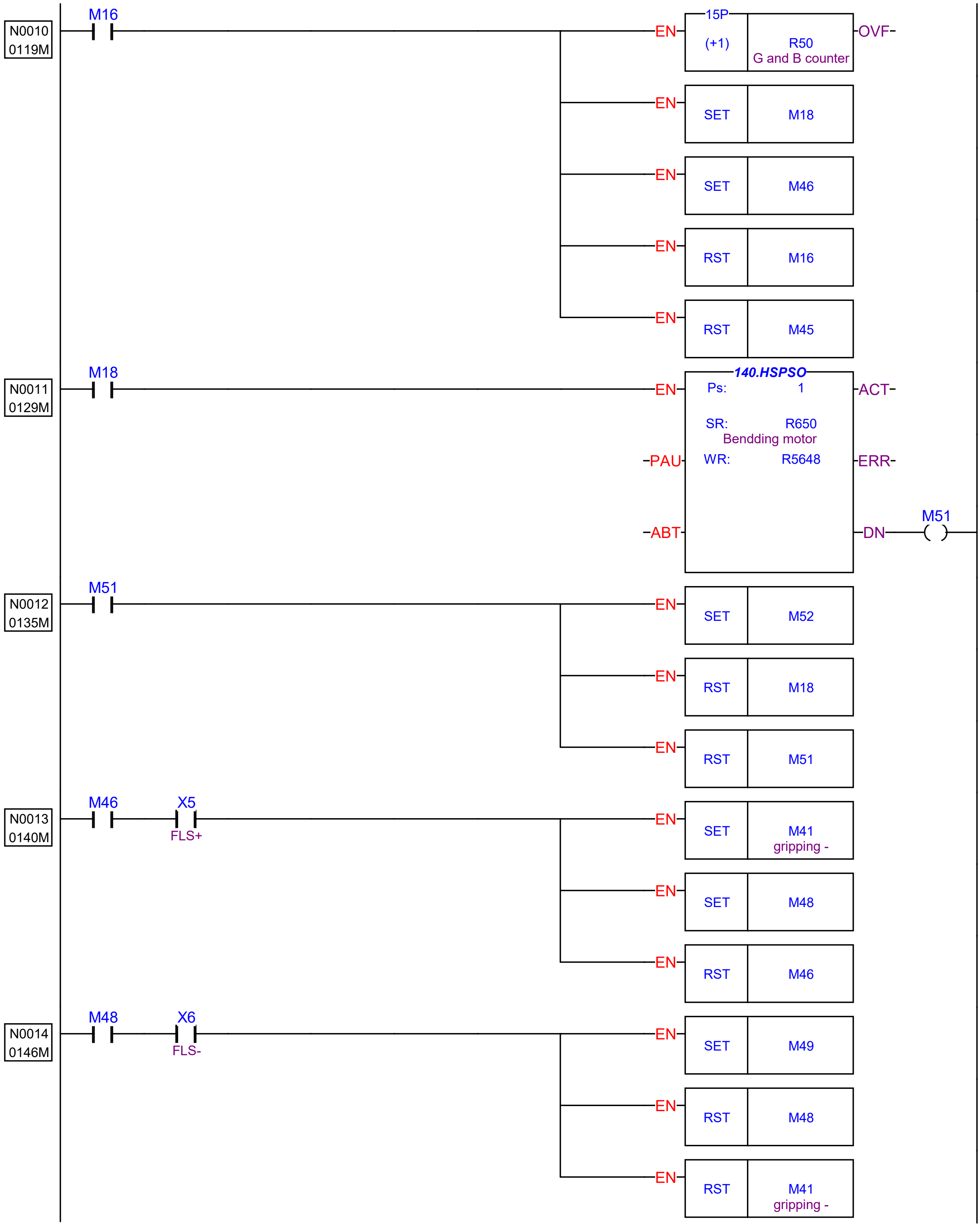

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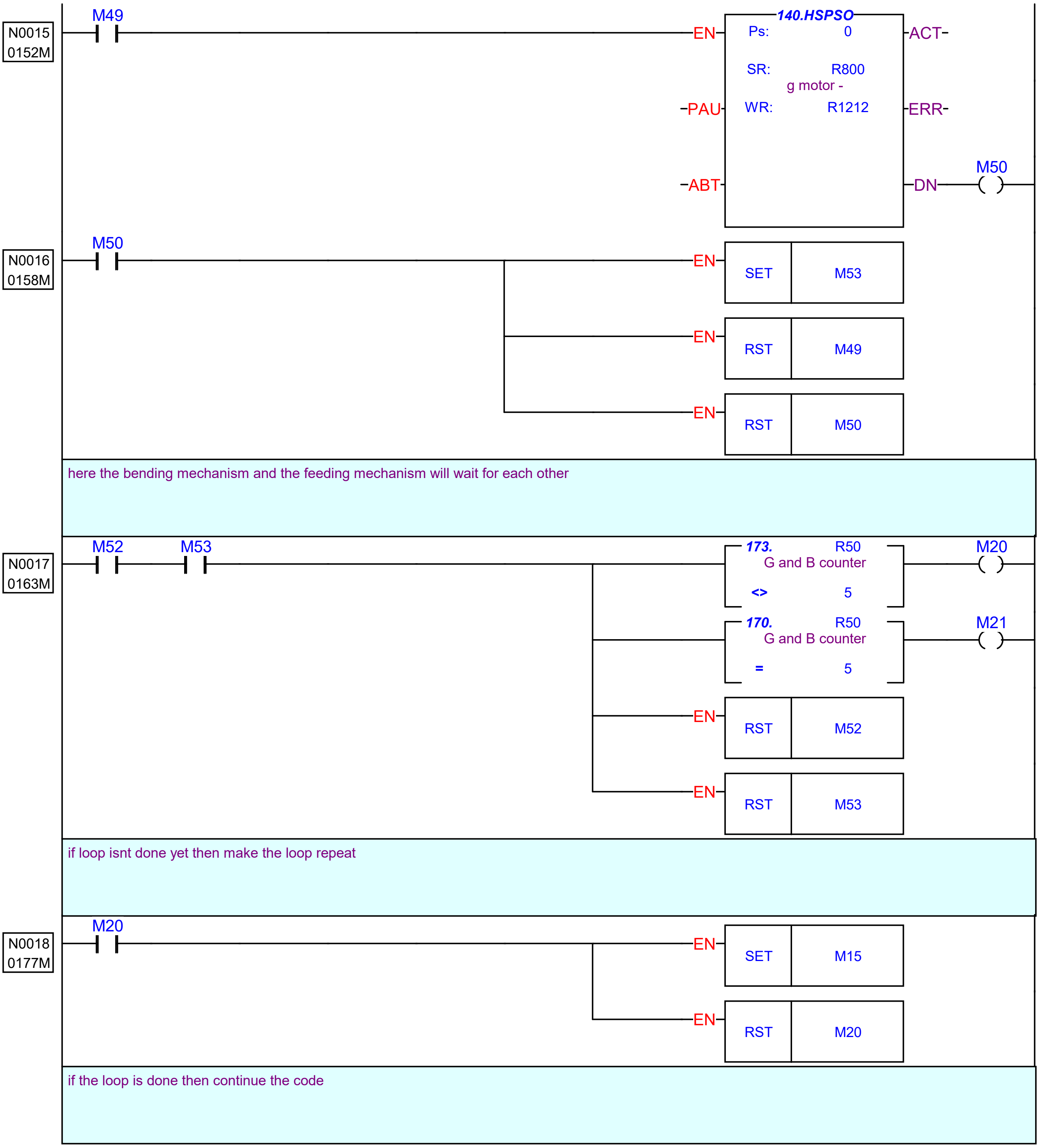

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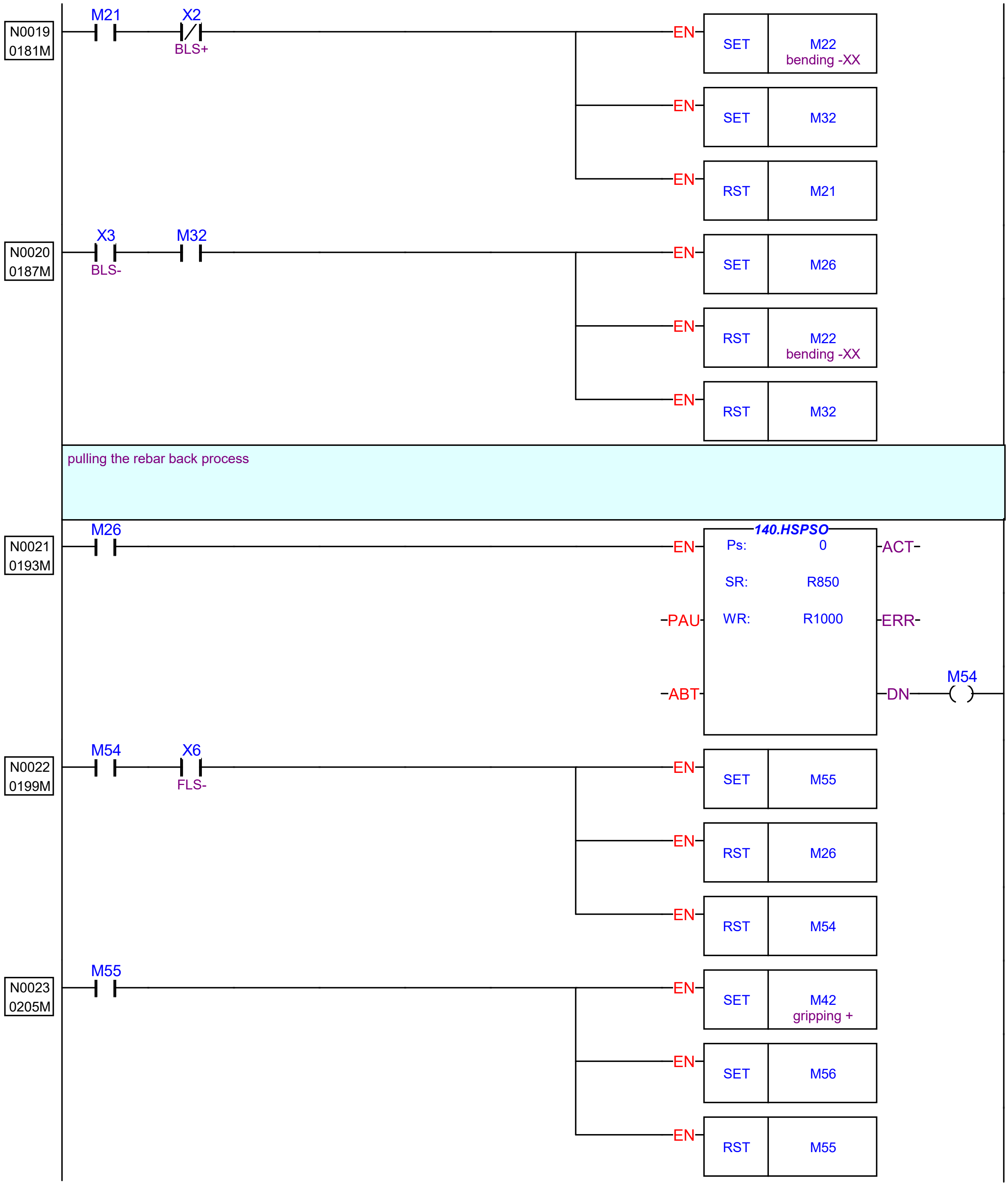

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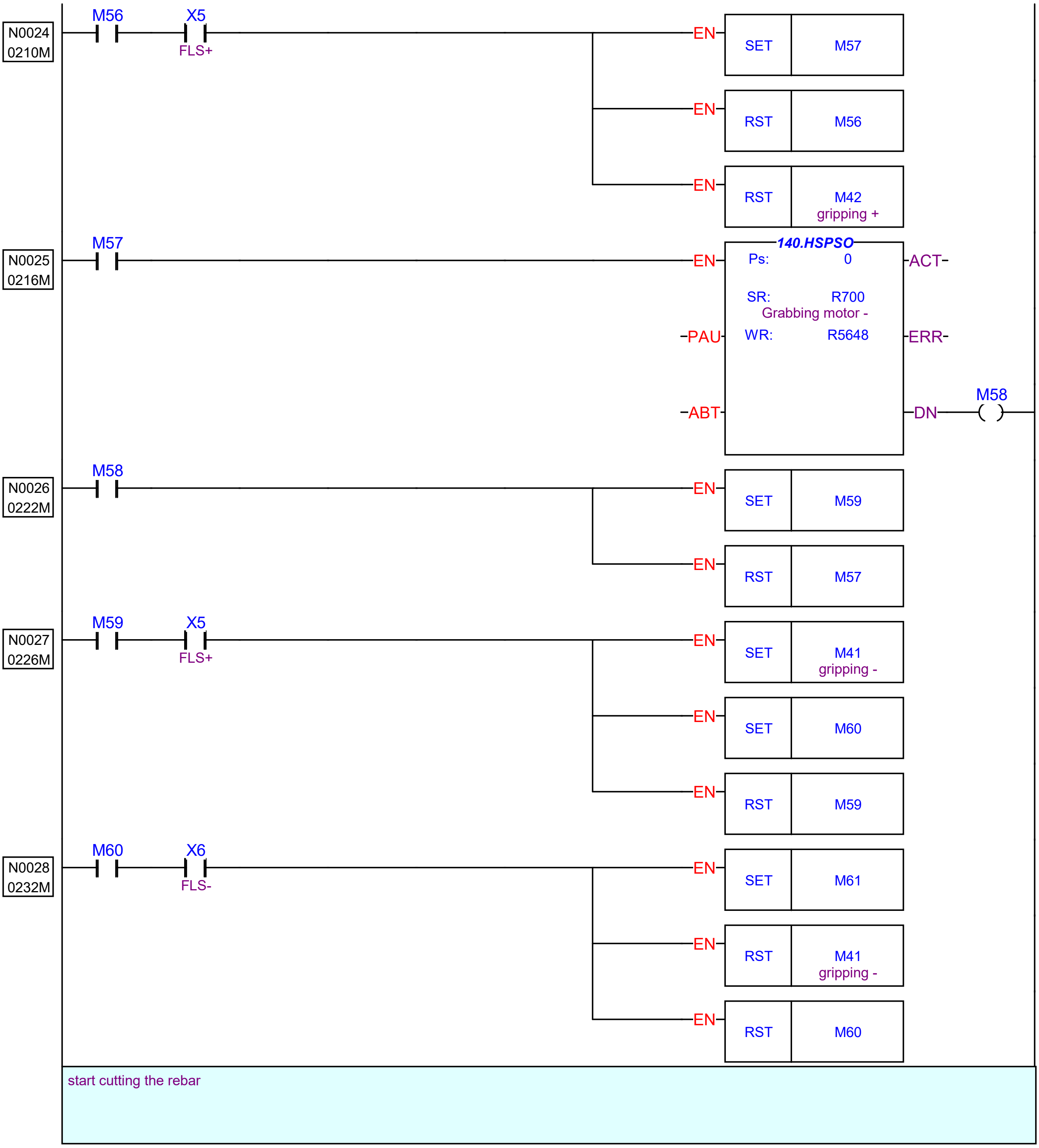

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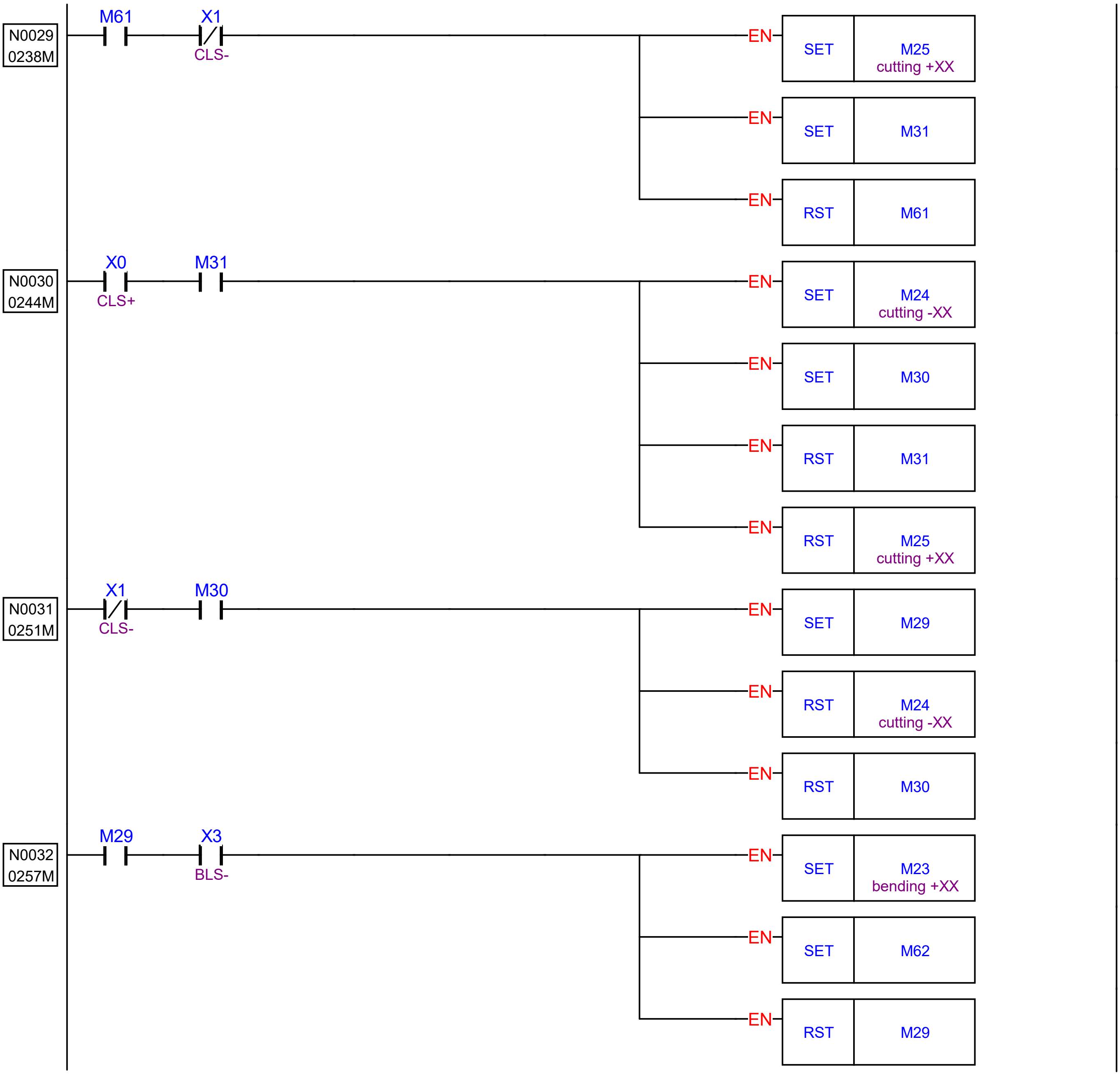

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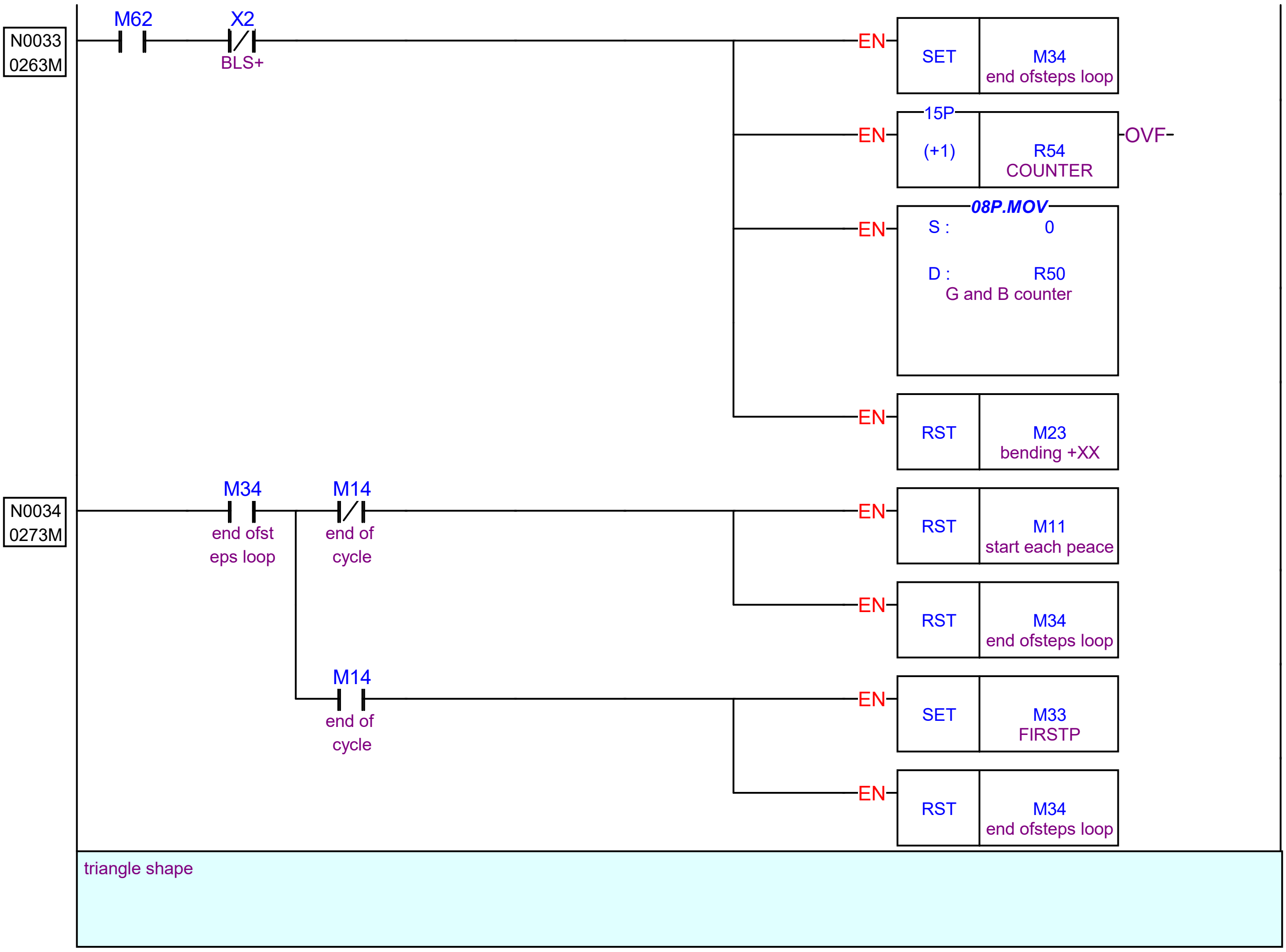

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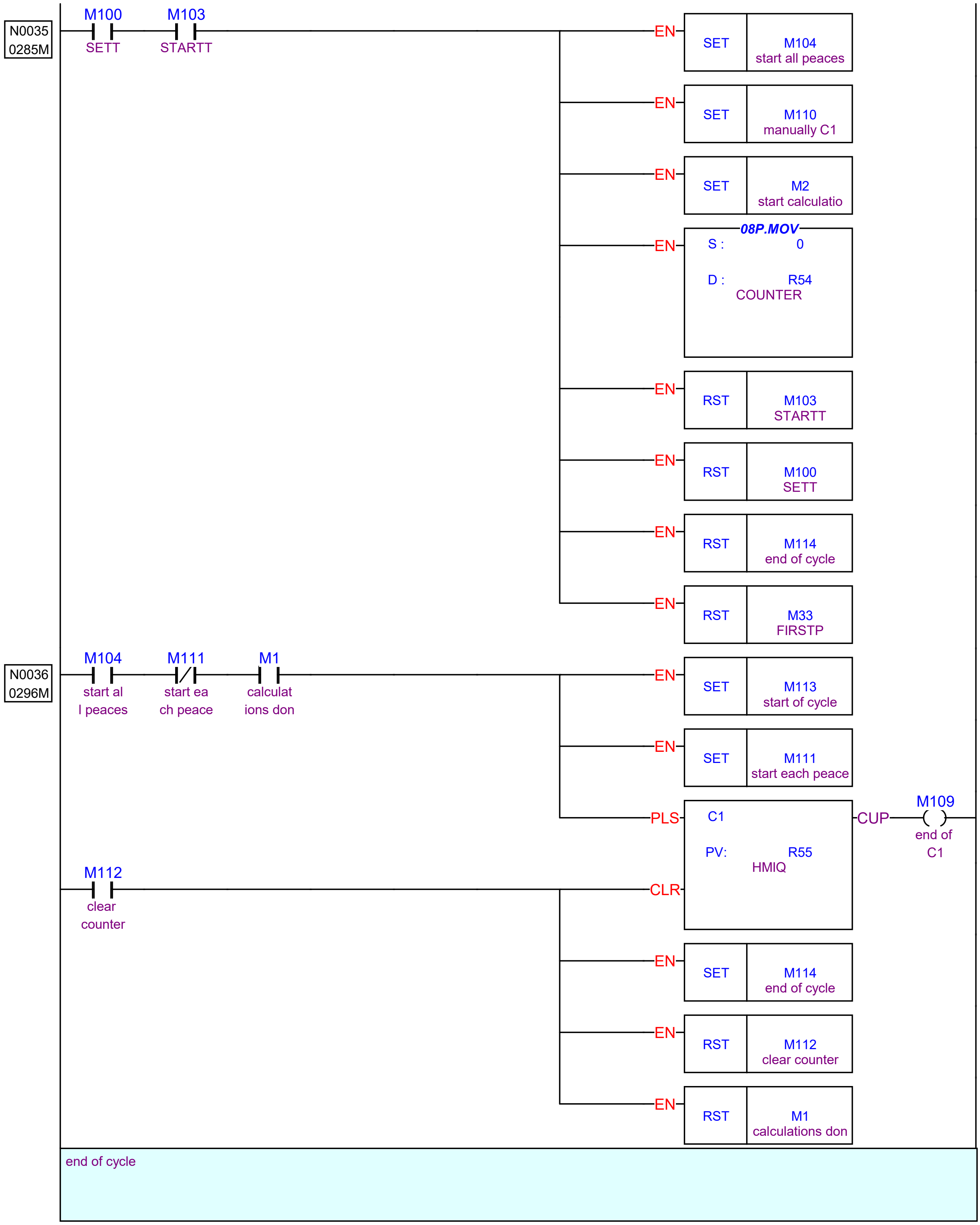

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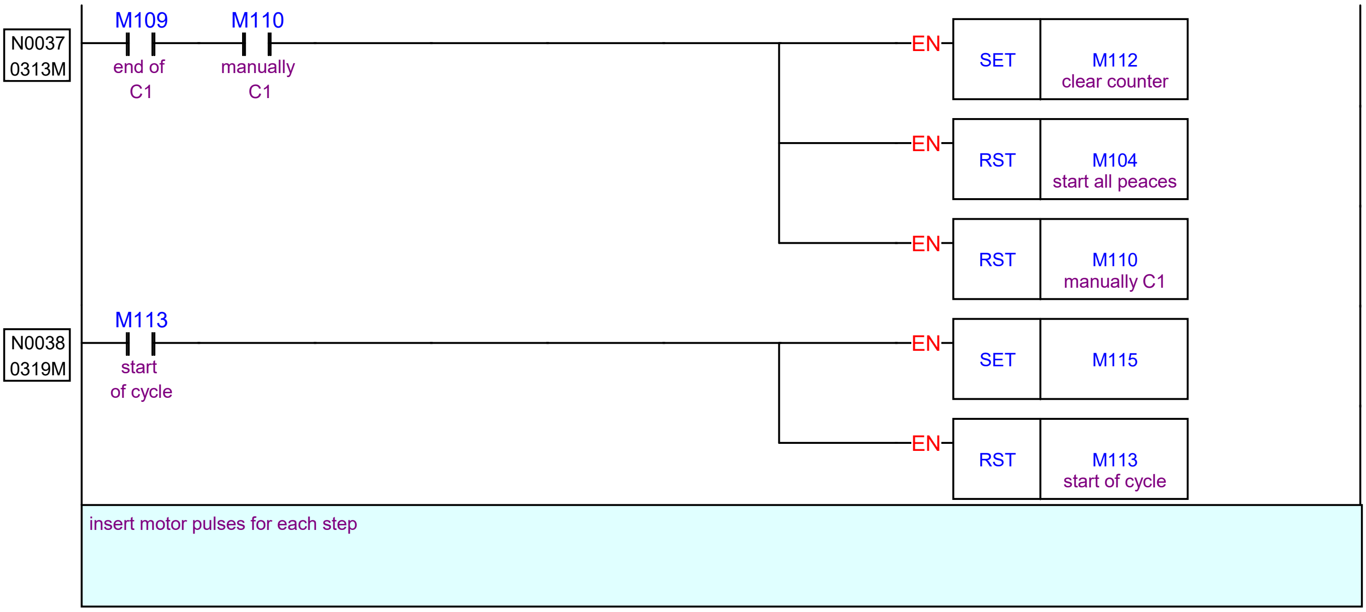

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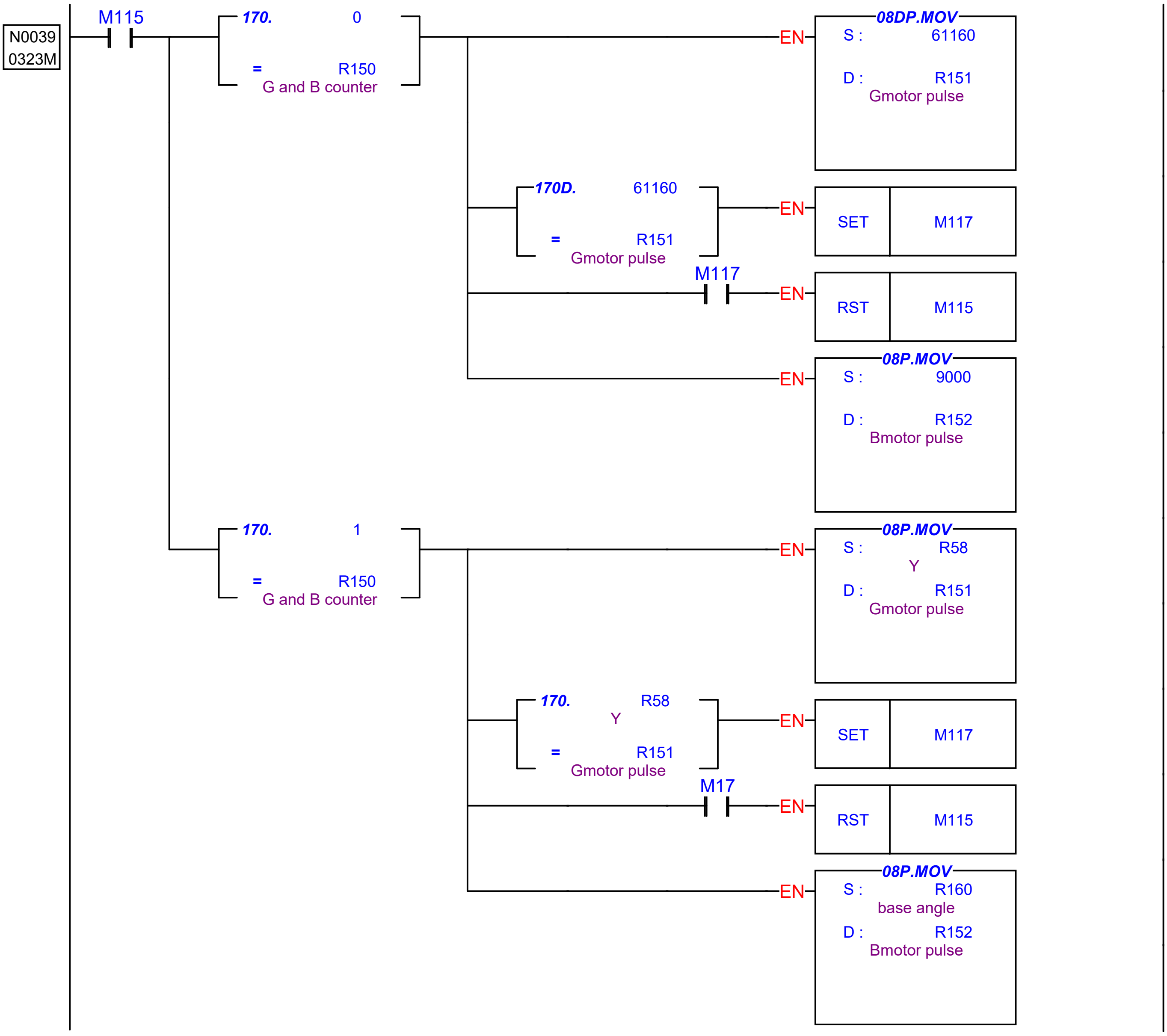

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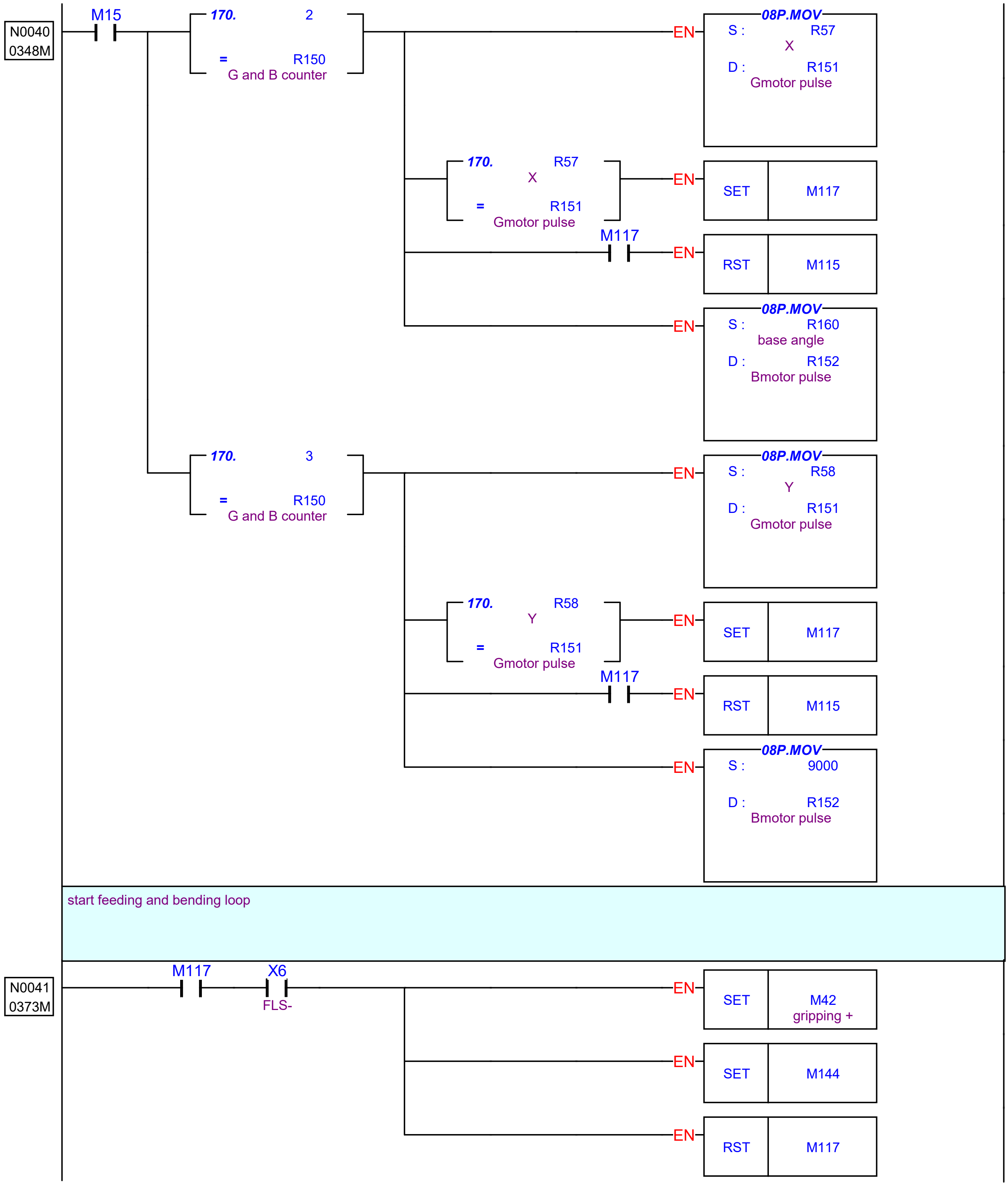

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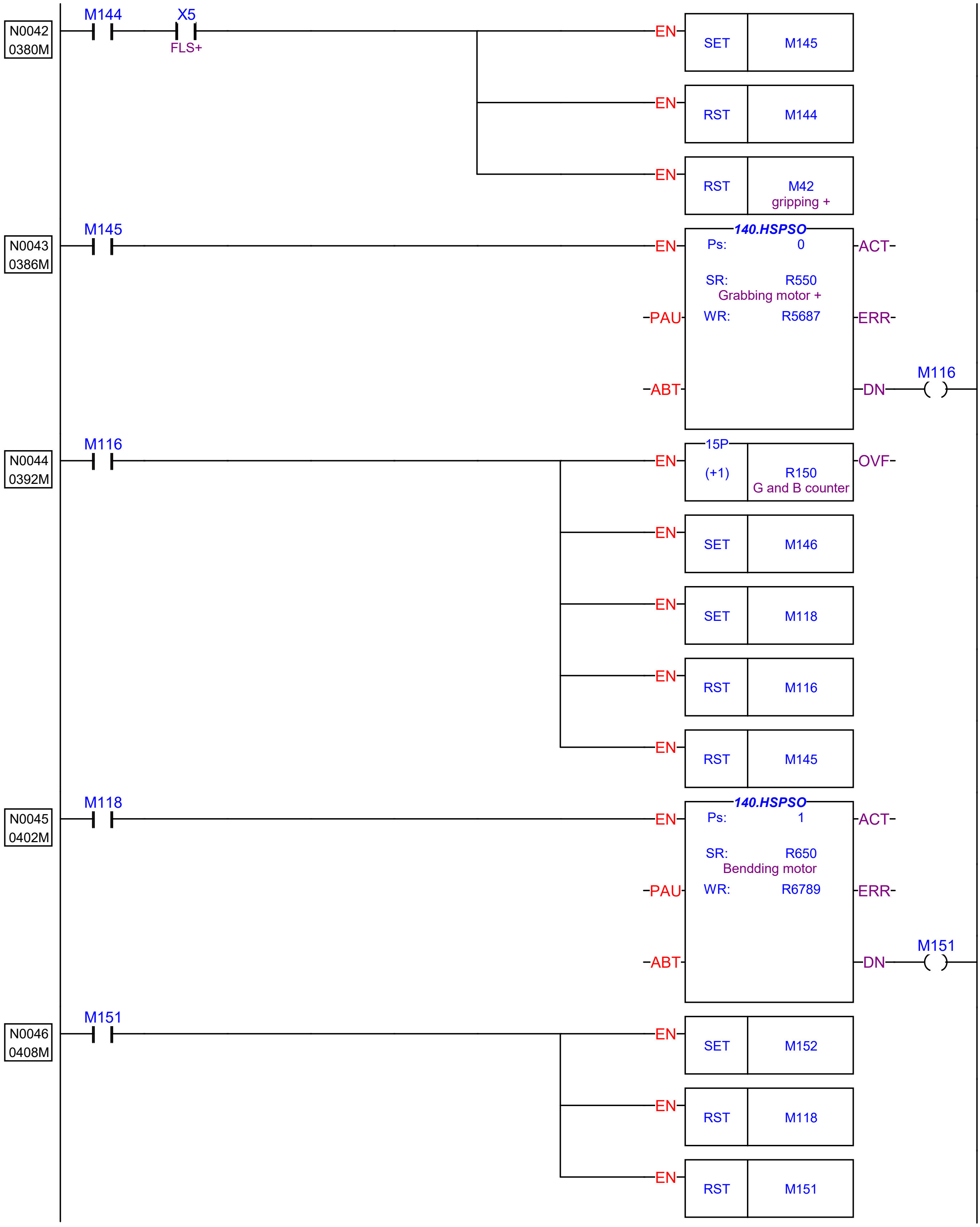

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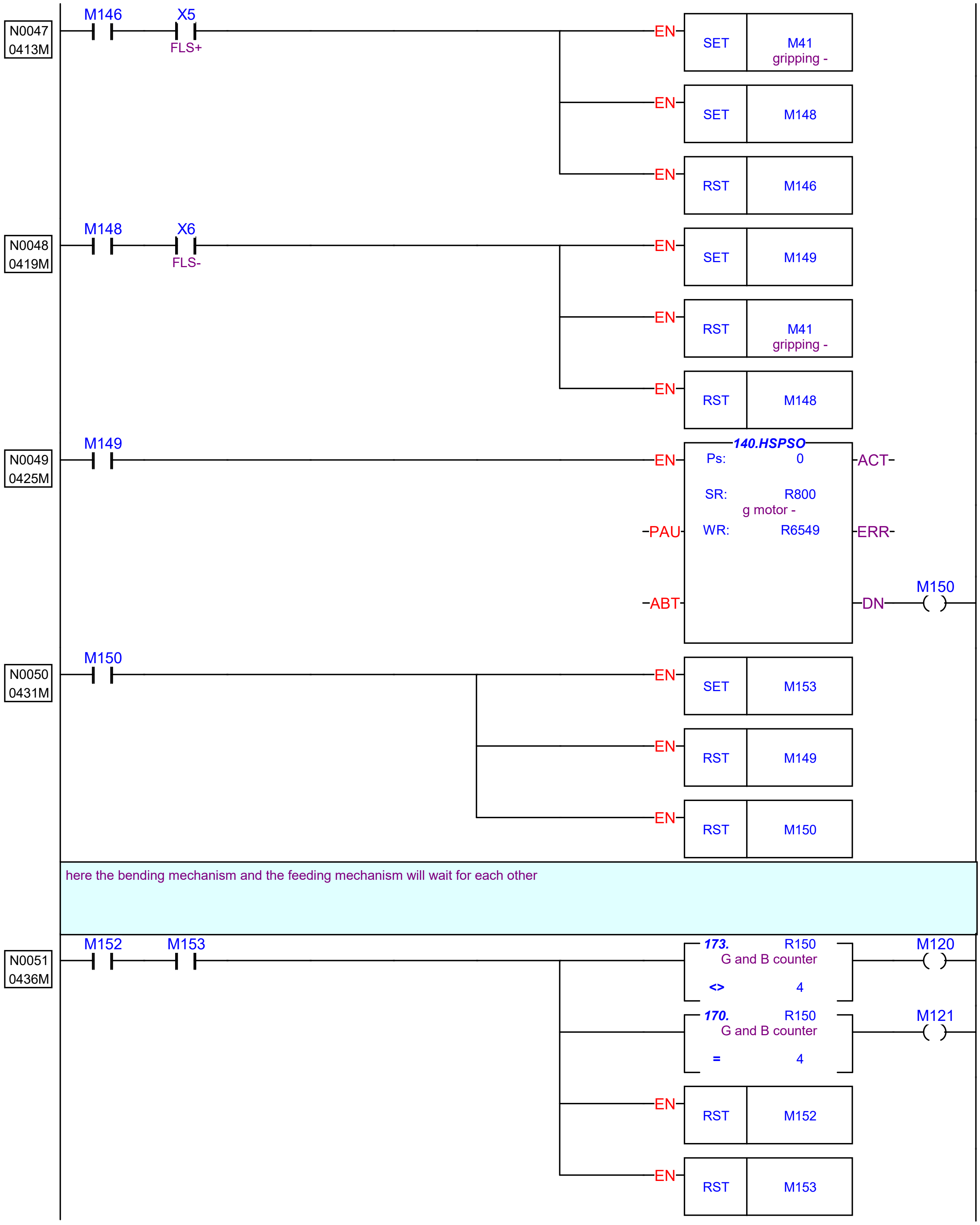

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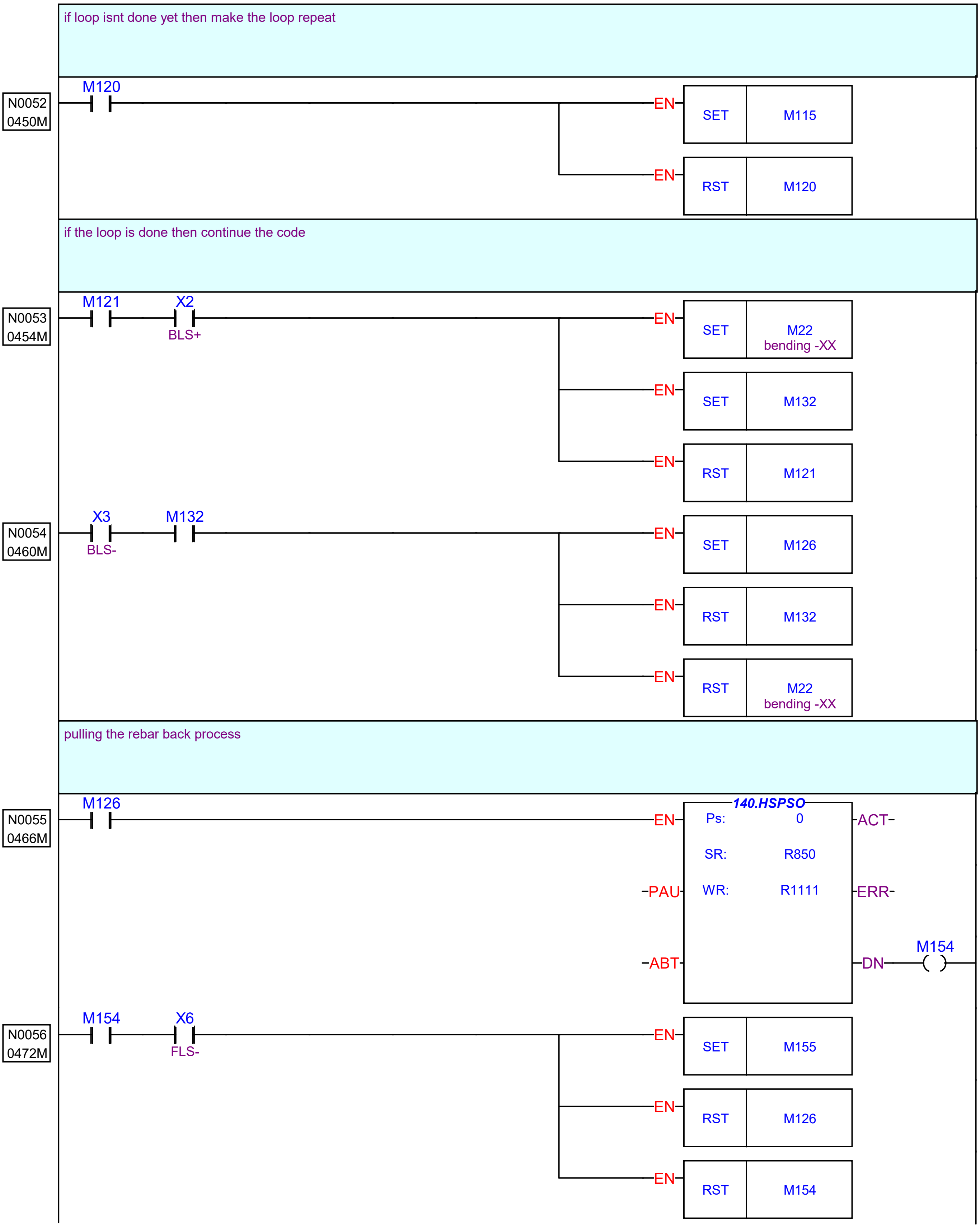

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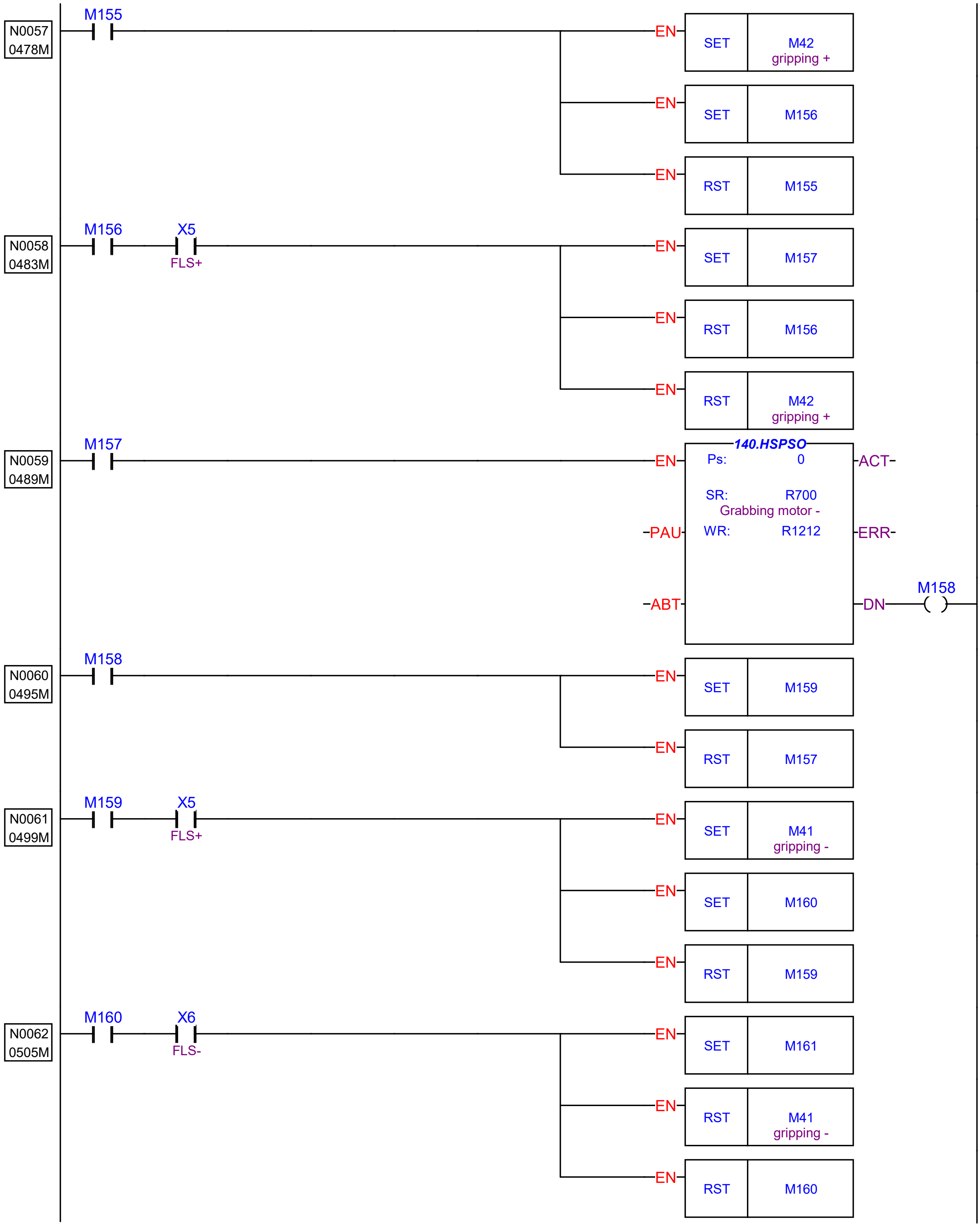

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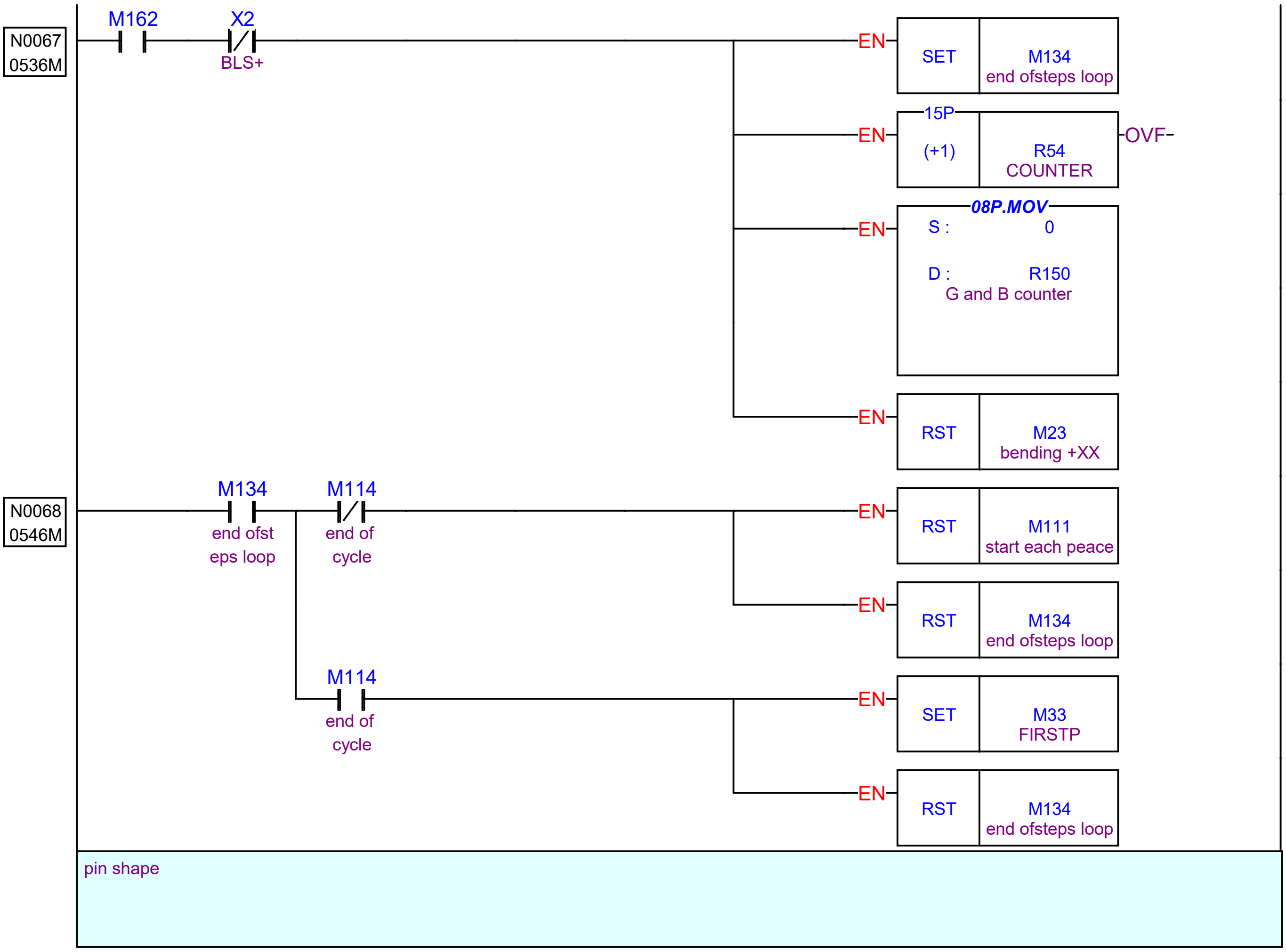

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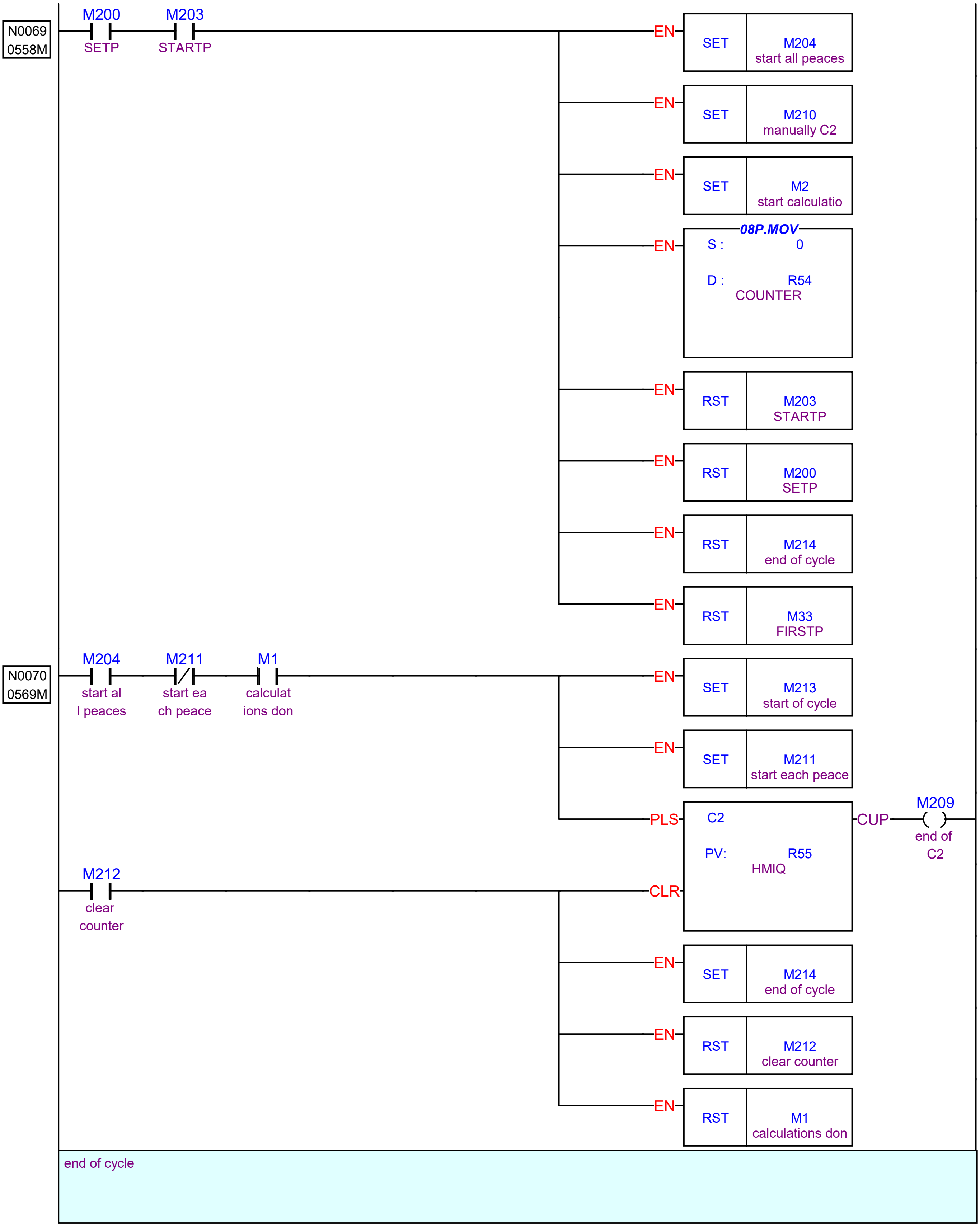

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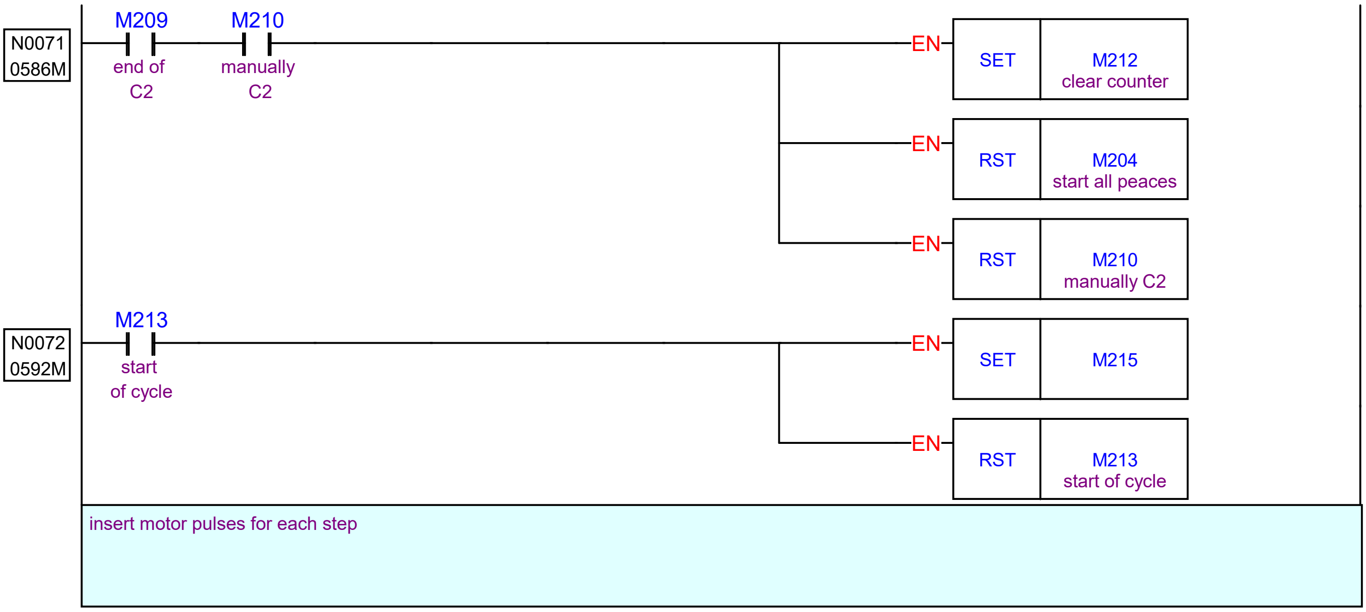

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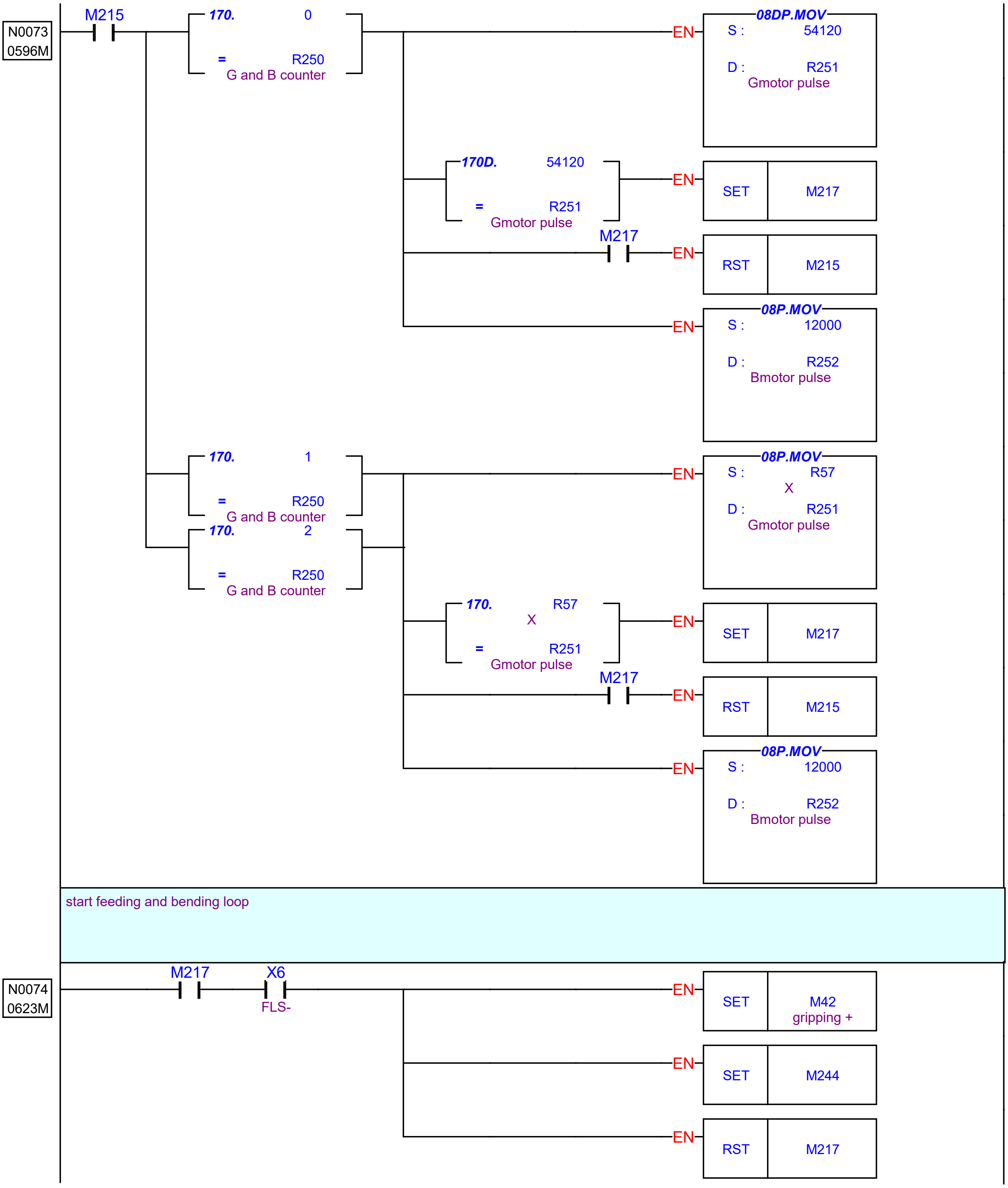

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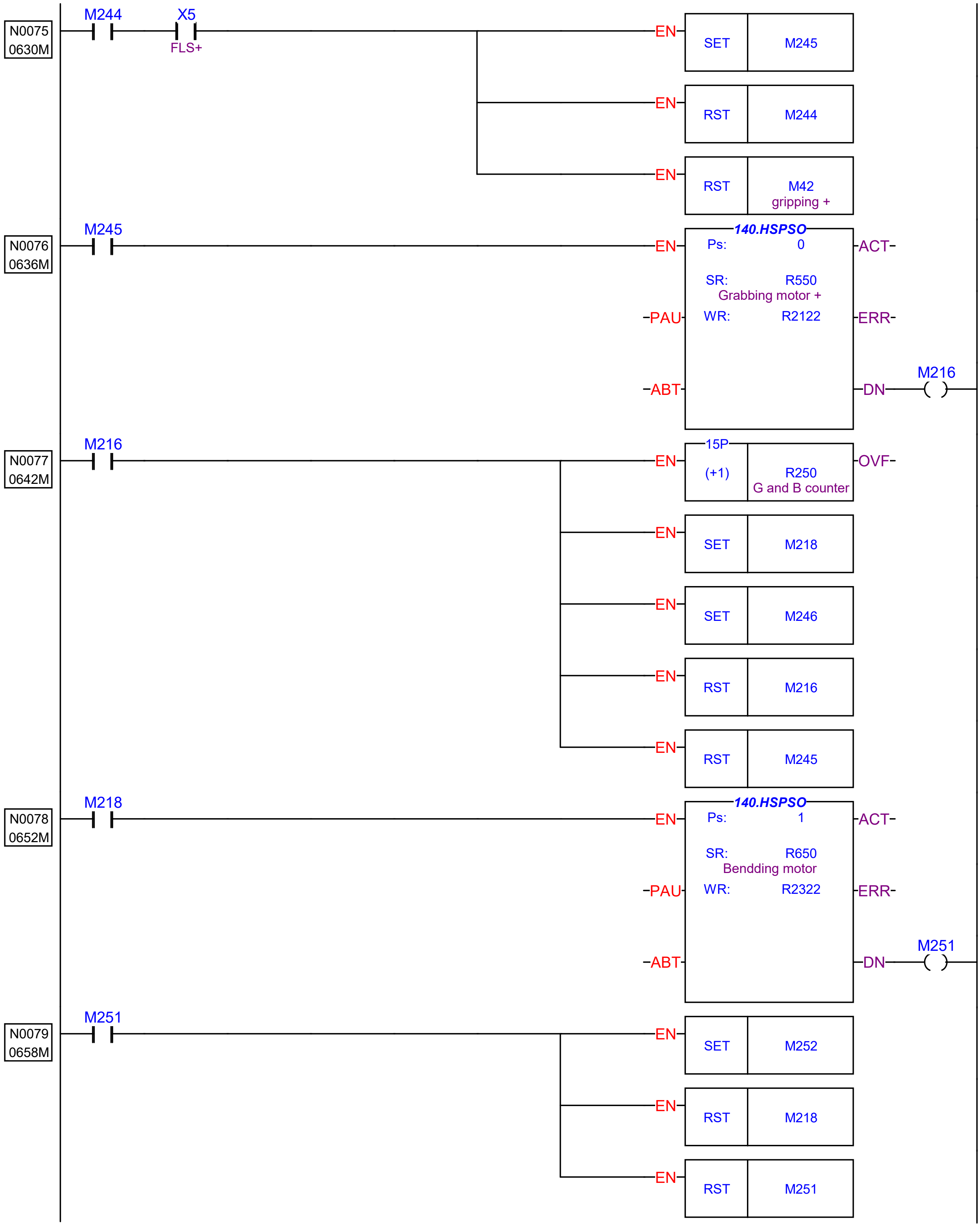

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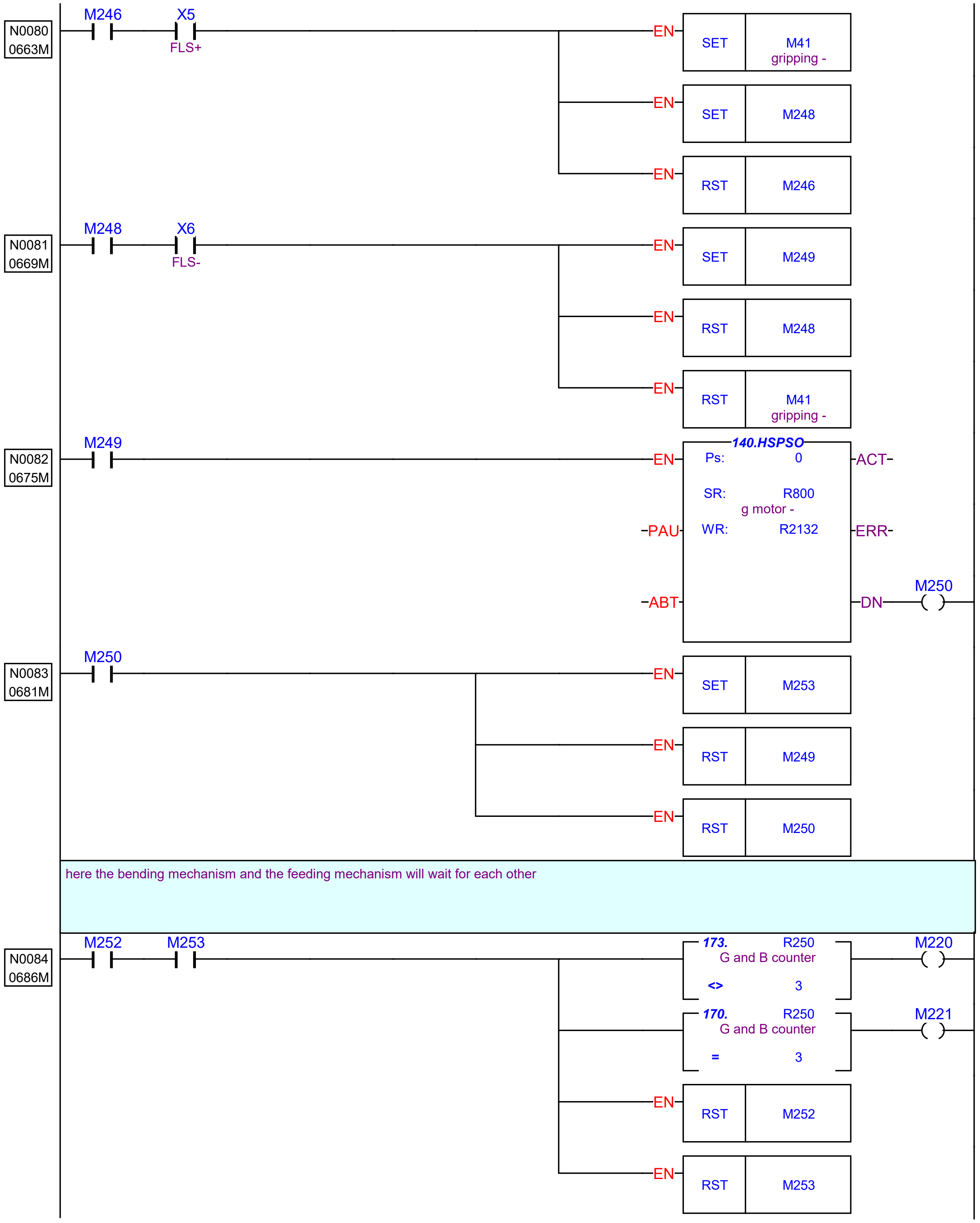

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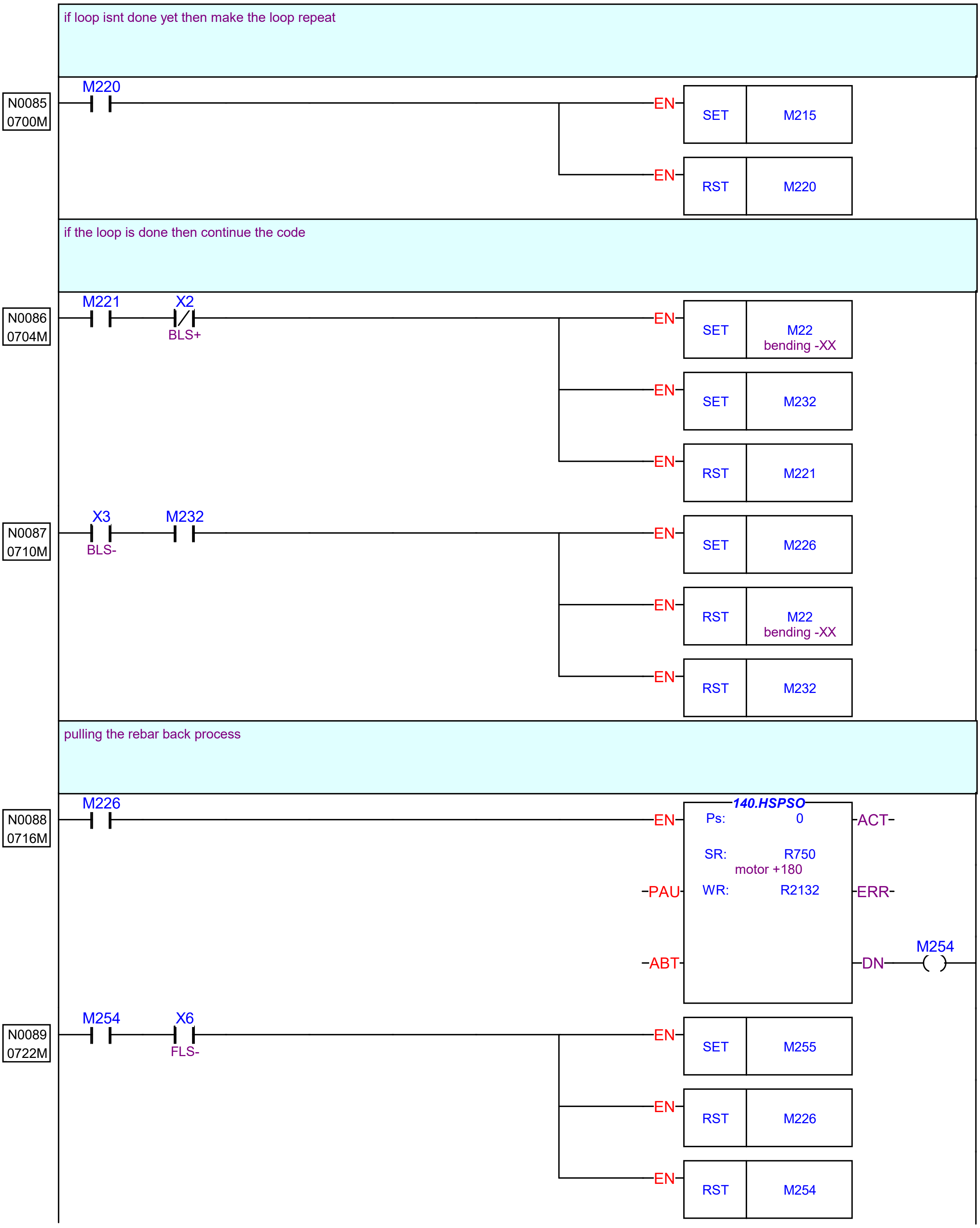

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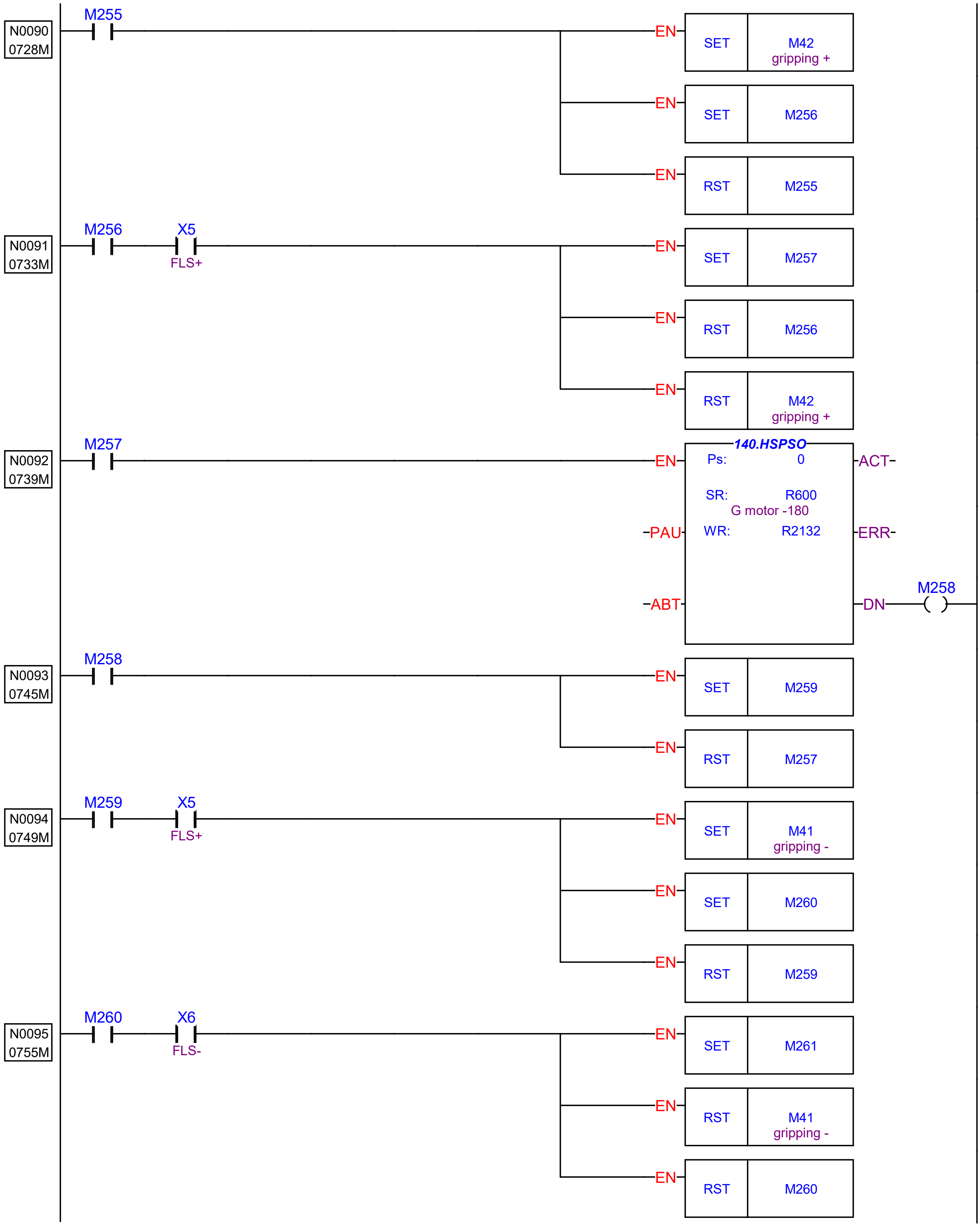

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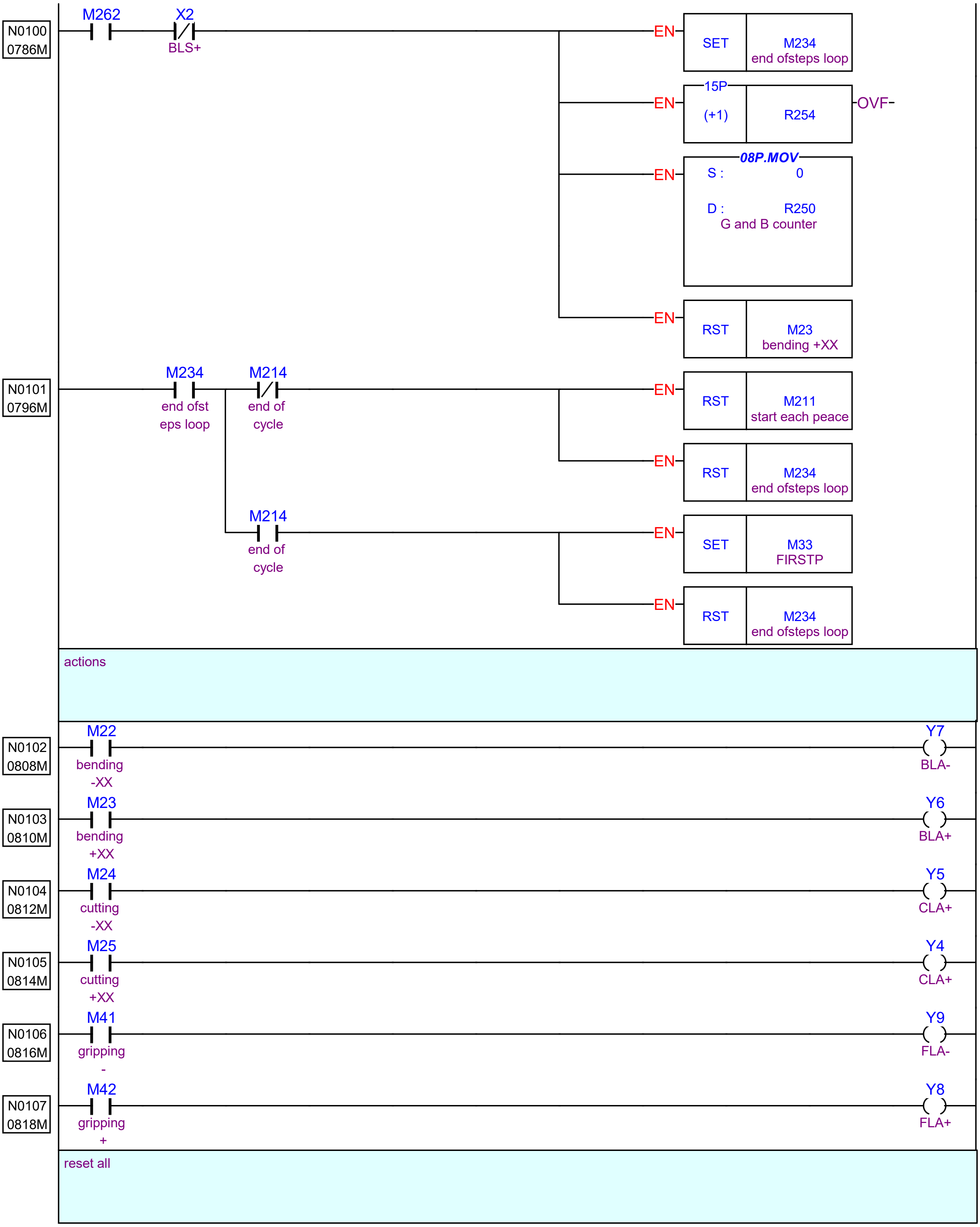

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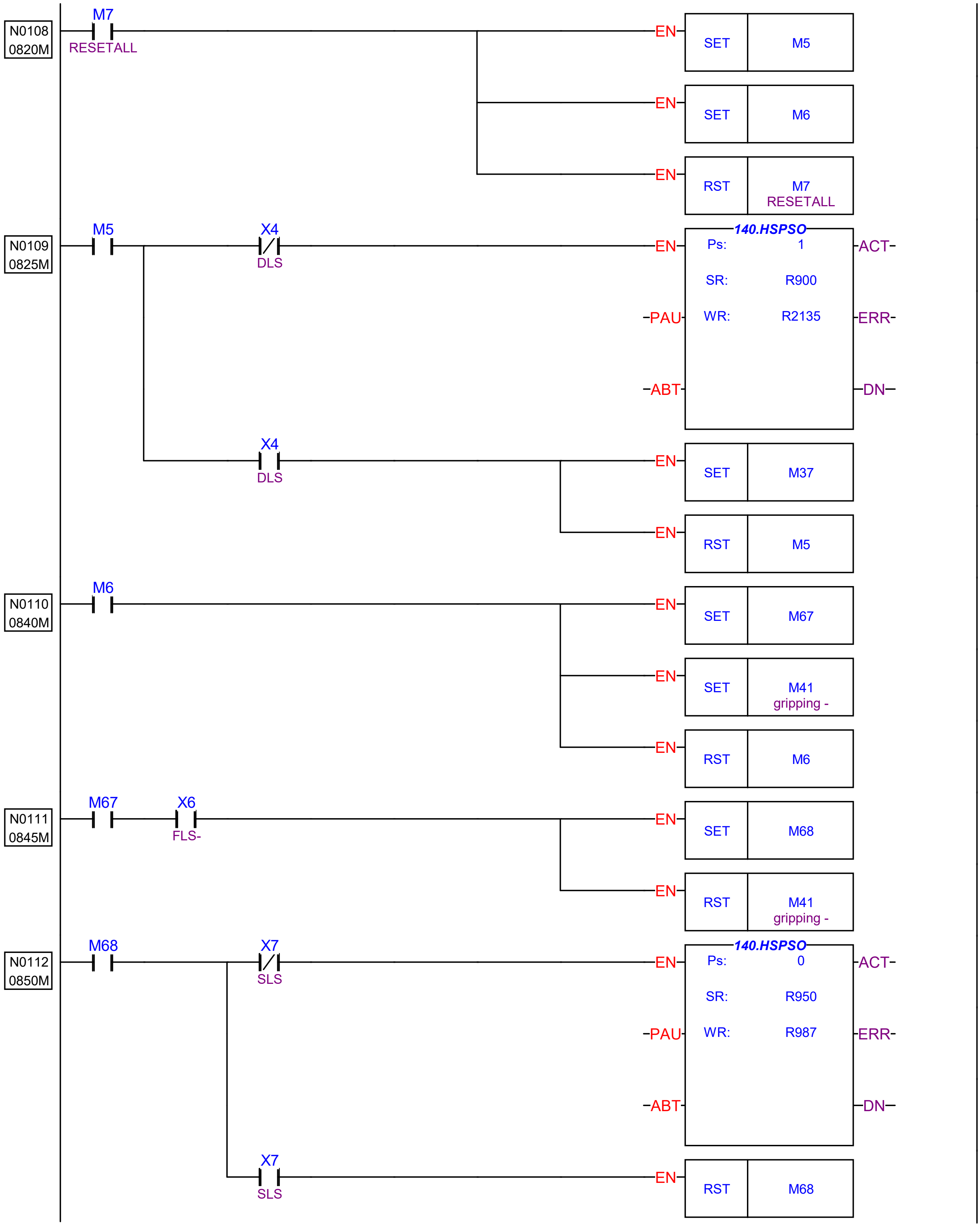

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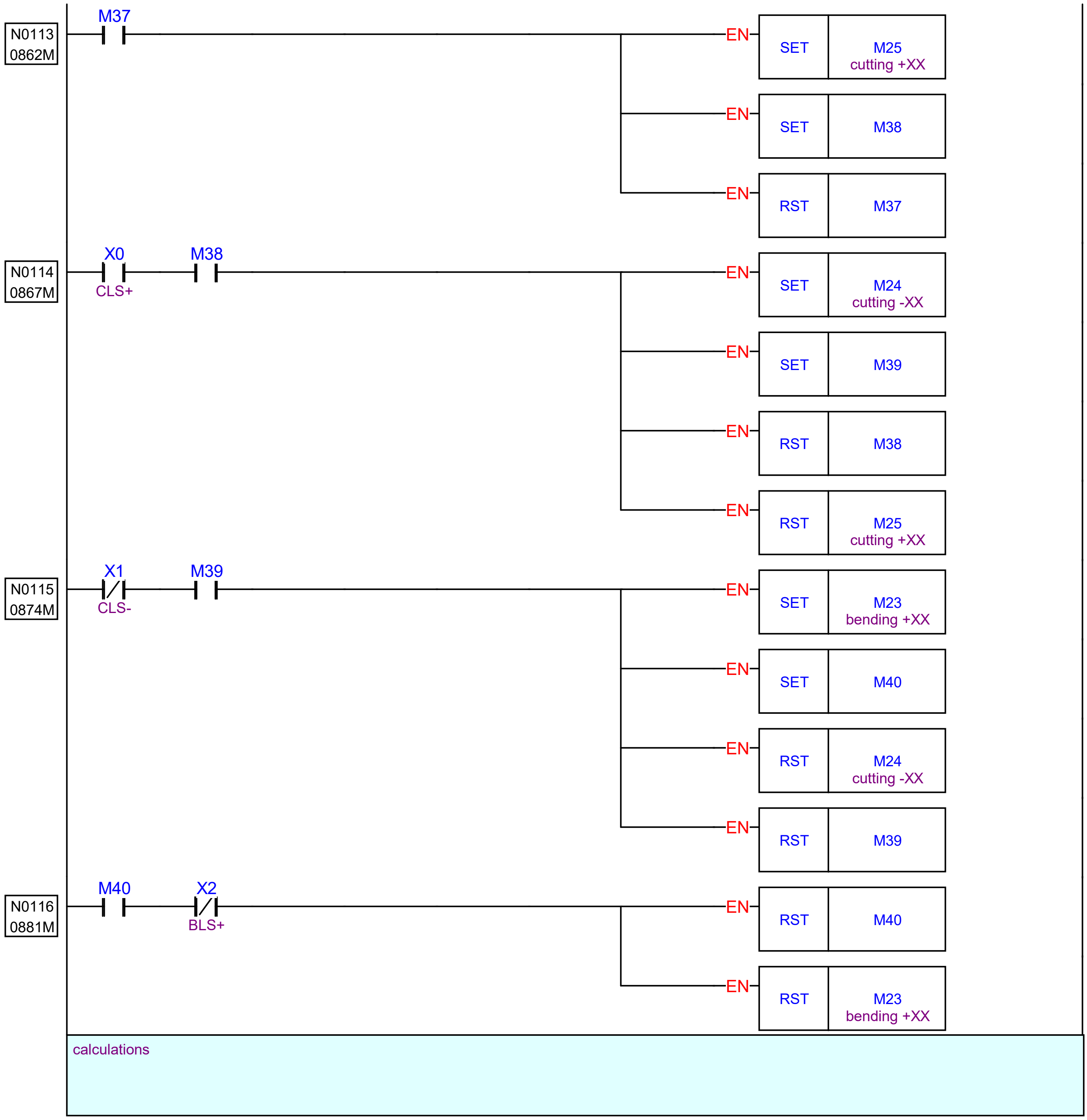

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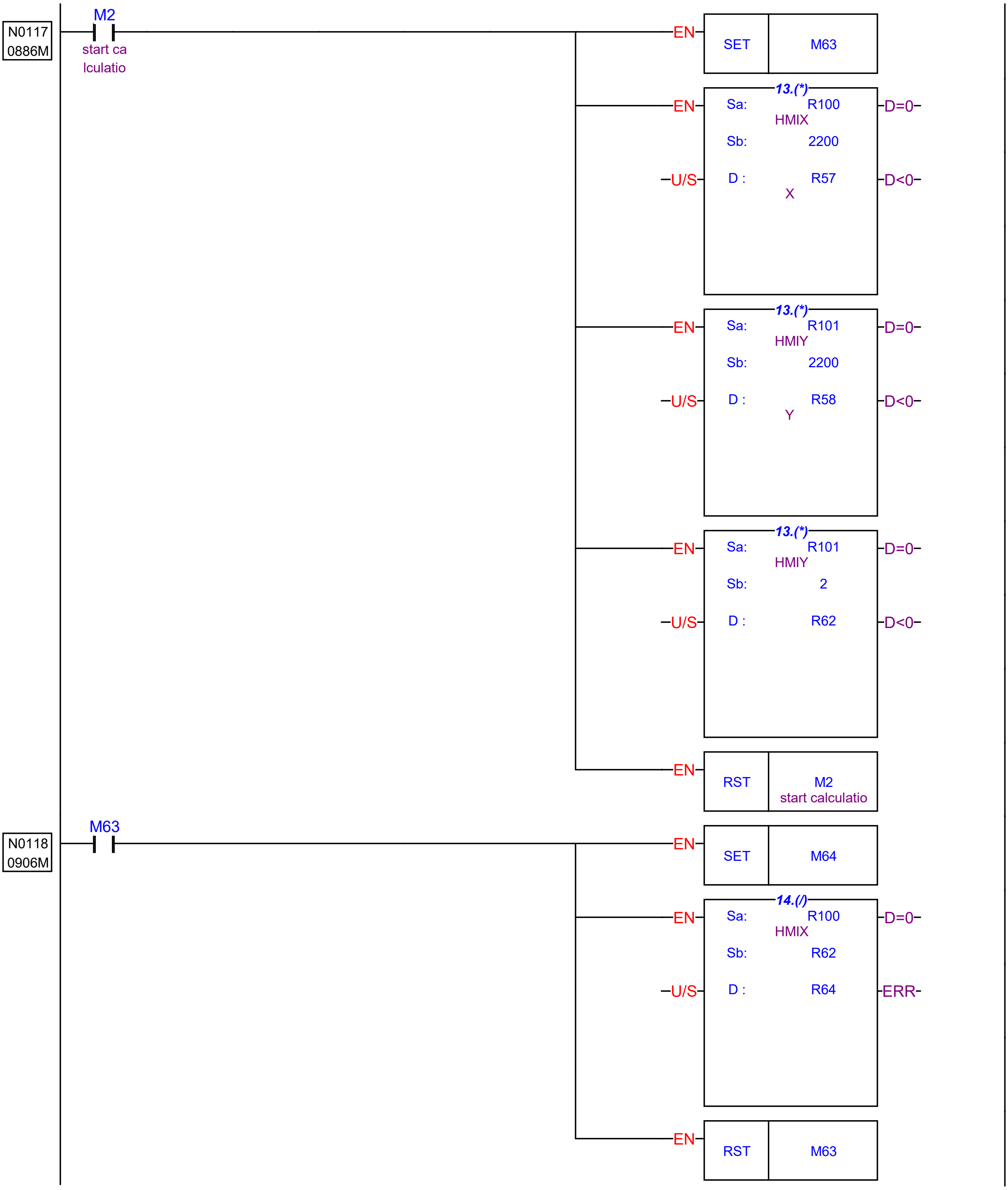

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