International Journal of Education, Science, Technology and Engineering
p-ISSN: 2685-1458, e-ISSN: 2684-9844

Original Research Paper

Analysis and Design of Coil Rolling Machines on Robot Solenoids using Macroergonomic MEAD and REBA Based on Arduino Microcontroller

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Article History
Received:
02.06.2020

Revised:
02.07.2020

Accepted:
12.07.2020

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Abstract: The making of Indonesian soccer robot in the division of the Indonesian Football Robot Contest (KRSBI) especially in the process of coil rolling machines on a solenoid does not pay attention to ergonomic factors. The process of winding the wire on the solenoid is done using only the hands manually and in an un-ergonomic body position, which is turning and bending. As a result, the convolution process lasts longer and in the wrong posture, causing fatigue and back pain. Macroergonomic Analysis and Design (MEAD) and Rapid Entire Body Assessment (REBA) approaches are used to analyze the posture of the wire. The solution is obtained by design and making an ergonomic and semi-automatic coil rolling machines to solenoid Robot based on the Arduino Microcontroller.

Keyword: Coil Rolling, Ergonomic, MEAD, REBA, Microcontroller.

1. Introduction

The Indonesian Football Robot Contest (KRSBI) is one of the divisions in the national intelligent robot competition. The making of Indonesian soccer robot in the division of the Indonesian Football Robot Contest (KRSBI) especially in the process of winding the wire on the solenoid so far does not pay attention to ergonomic factors. The process of winding the wire on the solenoid is done using only the hands manually and in un-ergonomic body position, which is turning and bending. As a result, the process of winding the wire lasts quite a long time, which is about 12 hours and in the wrong posture, so that it causes fatigue and back pain.

Some libraries are used as literature for this research. The first is the Design of Tofu Filtering Tools Design in the Tofu Making Process with the Macro Ergonomic Analysis and Design (MEAD) Method [1] with the problems in it. The problem that occurs in this study is that there is often damage to the screening equipment and worker fatigue that occurs in filtering activities that occur done. Some workers often feel pain in the back due to repetitive filtering work. Obtaining the results of the study are the proposed layout and new filtering tools to increase productivity and reduce fatigue and musculoskeletal complaints.

Furthermore, Research on the Selection of Enamel Wire for the Making of Eddy Current Dynamometers with Maximum Torque of 496 Nm [2] with the problem in this research is the edy current dynamometer consisting of the main part, namely the solenoid consisting of wire coil with wire which must be considered economically and technically. For the proper use of coil wire, the results of this study were selected in the form of Hellenic Mediotherm 200 enameled wire with a diameter of 1.05 mm (AWG 18). It has been tested that is tried for a solenoid that is able to produce a torque (τ) = 62.07 Nm with a wire length of 184 m or weighing 1.6 kg for a solenoid composed of 8 stacks of wire.

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The next library is the Design of Tofu Presses and Presses on Tofu SMEs Using the Macro Ergonomic Analysis and Design (MEAD) Method [4] with the problem in this study, namely fatigue that occurs in overworked workers and not yet optimal work systems that result in pain that becomes a complaint on the body caused by tools used in tofu printers and presses which are not yet ergonomic, the results of this research are getting variances to design the tofu press and presses. The variance used is the basis of the tool being repaired by referring to the dimensions of the body in order to obtain an ergonomic tool, ease and safety in using the tool

The next research is Workplace Analysis and Design Using the Macroergonomic Analysis and Design (MEAD) Method [5] with the problem in this study that is the number of complaints of pain in some parts of the worker's body when carrying out operator activities on the packing when lifting and lowering the ceramic box can , and obtain research results in the form of a design plan for operator packing worktable as a solution to the problem of packing ceramic into boxes that require operators to work by standing and bending.

Based on these libraries, to improve the process of winding the wire on the solenoid in the making of the Indonesian Football Robot to be more ergonomic and efficient, this study aims to analyze and design the wire wound device on the Solenoid using Macroergonomic Analysis and Design (MEAD) and Rapid Entire Body Arduino Microcontroller-based Assessment (REBA).

2. Basic Theory

2.1. Solenoid

A solenoid is a basic device that converts an electrical signal into mechanical motion [6] Where a solenoid consists of a voltage or current rating coil and a suction or booster when given a certain voltage the suction can be a spring or rubber that is used to reverse the state after the coil that occurs , impulse occurs due to the electromagnetic force that occurs when a solenoid is electrified or when an electric current flows inside the solenoid will produce a magnetic field, this magnetic field will push the plunger inside the solenoid out which will push the kicking leg.

2.2. Coil Rolling

The wire used is enamel wire with a diameter of 1 mm. In the process of wire welding there are a few things to know including wire diameter, length of wire required, number of turns, core diameter, wire weight or solenoid [2]. Enamel wire is a copper wire that can transmit conductors but out of copper uses coating material as an insulator

2.3. Coil Rolling Machines

The tool that will be used to wrap the enameled wire on the solenoid is a tool that can do the coil needed to design the solenoid, as needed in the number of turns. The device will be adopted an automatic system consisting of an arduino nano microcontroller [7] which is used as a controller for the PG45 motor driver, and a DC motor and display display using a 16x2 LCD as well as input from the sensor to calculate the turns, then mechanical design of the tool is carried out with due regard to aspects the value of ergonomics, aims to produce ergonomic work tool designs. With the ergonomic work tool design, it can effectively support the activities carried out [4].

2.4. Ergonomics

Ergonomics is the study of various aspects of life and the characteristics that exist in humans as a process of human interaction with the objects used, the work environment and all aspects related to the work done, of course by paying attention to safety, health, and job satisfaction [8]. It can be concluded that ergonomics is a science that is used to design things in life to feel comfortable and contain high efficient and effective value.

2.5. Antropometry

Antropometry is a method of designing a tool design in order to obtain ergonomic value and has a function that is not too wasted in its use. According to [8] anthropometry comes from the word anthropos which means human and metric which means measurement. It can be interpreted that anthropometry is a study related to the measurement of dimensions in the human body in accordance with existing proportions. Humans have different shapes, dimensions of body dimensions, anthropometry is used as ergonomic considerations in measuring the dimensions of the human body and human interactions with the objects used, in the measurement using percentile statistics commonly denoted P is a point or value that divides a data distribution into one hundred equal parts. The points that divide the data distribution into one hundred equal parts are the points P1, P2, P3, P4, P5, P6, and so on up to P99, the 95th percentile will indicate that 95% of the population will be at or below the size the. While the 5th percentile will indicate that 5% of the population will be at or below that size. In anthropometry. The 95th percentile will represent the "biggest" human size and the 5th percentile will represent the "smallest" size. It can be concluded that the percentile is the number of parts per hundred people of a population who have a certain body size (smaller or larger) [9]

2.6. Macroergonomic Analysis and Design (MEAD)

Macro Ergonomic Analysis and Design (MEAD) is a method related to designing, analyzing, and evaluating work systems in organizations so that they are effective and efficient [10]. MEAD method there are several stages, namely:

1. Define the organizational subsystem
2. Defining work systems and performance levels. Define key performance to be achieved and the desired level of performance.
3. Defining operating units and work processes
4. Identify Variants
5. Make a variance matrix
6. Analyzing personal roles
7. Determination of function allocation and design integration
8. Analysis of perception and responsibility
9. Redesigning work systems and facilities
10. Implement, iterate, and improve performance

In a previous study of MEAD, it was explained that the macroergonomic approach could also be used in the design of work tools that could assist in performance [1], this method was also used as a redesign of the design of truck driver seats and truck kernets that experience excessive fatigue when driving by obtaining results to the draft of the proposed expedition truck driver seat for PT.Maju

Bersama that is in the form of designs that have followed the wishes of the driver, the needs of the driver and the wishes of the company, as well as based on anthropometric values and ergonomic principles. For this reason, the design of the new driver seat structure will have a better function and value than the old truck driver seat [3], it was found that research using the MEAD method can change people's behavior by creating a samoah place design using a macroergonomic approach [11]

2.7. Rapid Entire Body Assesment (REBA)

Rapid Entire Body Assessment (REBA) is one of the methods used in analyzing work based on the position of the human body, generally this method is used to evaluate posture, strength, activity and coupling factors that can cause repetitive injuries [12]. Where in data processing is divided into 13 steps with 2 analyzes:

1. Analysis on the neck (neck), back (trunk), and legs (legs)
2. Analysis on the upper arm (upper arm), lower arm (low arm), wrist (wrist)

3. Research Method

The design of a wire wound tool on a solenoid by the author by carrying out the stages of the MEAD method, namely: defining organizational subsystems related to systems within the organization, defining work systems and work levels, defining work operating units and analyzing work processes, identifying variances that occur, creating variance matrices , analyzing the role of personnel, showing the allocation of functions and combining designs, understanding perceptions about roles and responsibilities, redesigning systems and work facilities, implementing, integrating and improving work. In the fourth and fifth stages, REBA analysis is carried out to identify variance and create a variance matrix. In the ninth stage, the design of a wire wound device on an Arduino microcontroller-based solenoid is created. After implementation, a discussion is carried out to discuss and evaluate the resulting improvements.

4. Result and Analysis

4.1. Defining Organizational Subsystems

At this stage the organization's subsystem definition is related to robots in the KRSBI division by focusing on the basic principles of its work. The robot contained in the KRSBI division is a robot used in soccer robot competition, which consists of 3 robots, namely 1 goalkeeper robot and 2 attack robots. Robot mechanics are generally designed to get stable and fast movements, based on the ease of regulating movement and speed. In this robot uses 3 active wheels so that the robot does not lose balance when the robot dribbles the ball and laying compass compass that is used as a direction for the robot that is placed on the top of the robot with the aim that is not affected by the magnetic field on the DC motor used in the robot as a propeller rooda so that the direction of the robot's movement is not error. The subsystems are arranged in the KRSBI robot which are the system components for running or moving the robot including:

- Mechanical systems or movers formed in robots
- Robotic kicking system (solenoid)
- Control systems (electronics, programs)

4.2. Define Work Subsystems and Work Levels

In the work system that occurs in the KRSBI robot consists of parts contained in the robot including for the movement system on the robot, namely:

- 5 active wheels, that uses 3 DC motors which are designed for the stability of the robot in walking and moving swiftly. Then 2 DC motors are used to dribble the ball stably on the ball hadling
- The design of the motor mounting in an independent manner on each wheel aims to make the robot's movements more varied.

The robot section in the control system, using the Arduino Mega2560 microcontroller, Arduino nano, mini PC and there are several sensors that are constrained simultaneously in order to reduce the workload of the microcontroller and facilitate the division of labor.

- The robot part of the ball kicker system, where this system is one of the core elements of the robot game with accuracy and speed to kick the ball in order to penetrate the opponent's goal, of course there are several things contained in this system as a supporting component in kicking, including solenoids , plunger, spring and stainless plate

- Solenoid, as already explained on the basis of the theory of solenoid, is the main driving force in kicking the robot which is composed of a loop of enameled wire in a circle of PVC pipe radius that has been arranged as a solenoid skeleton, where the root cumidies are electrified on the wire to produce a magnetic field will push the plunger
- Plunger drive plate stainless which is used as a booster to kick the ball
- Stainless plate is used as a foot in the robot in kicking the ball with rubber coated and formed according to the ability to kick.

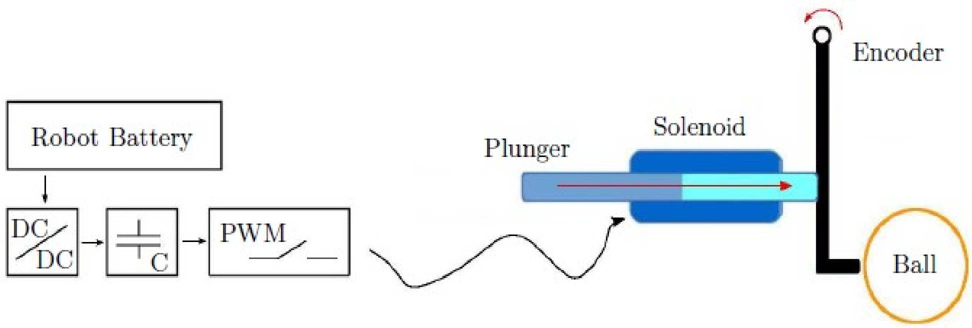

Figure 1. Solenoid Robot Work System

4.3. Define Work Operation Unit and Work Process Analysis

The work process analyzed in this study in the KRSBI Division is about problems that occur related to the process of coil rolling for a solenoid that is used as a robot kicker. Regional and national level competitions by the Directorate General of Higher Education (DIKTI) which are held once every 1 year, but in the preparations needed in the making that is ± 6 months before implementation, starting from the required mechanical design, electronics needed to the robot program according to the rules set. Among the work performed there is work considered to be less efficient, namely manually coil rolling to the solenoid, with the total number of turns that must be produced as many as 1187 turns so that it takes a lot of time and hinders the work, while the amount of resources is very minimal to do various things regarding preparation in making robots.

Table 1 shows a summary of the coil rolling work processes.

Table 1. Summary of the Wire Wound Process

Summary		
Activities	**Numbers**	**Minutes (hours)**
○ Operation	11	560 (9,3)
D Waiting	2	90 (1,5)
□ Inspection	4	70 (1,1)
Total	**17**	**720 (12)**

4.4. Identify Variants

In identifying variances or problems that arise, then the assessment of work posture is performed using REBA (Rapid Entire Body Assessment), which is by grouping several members of the body to then be given a score related to the relationship. In the assessment using the REBA (Rapid Entire Body Assessment) sheet there are several sections analyzed in it, the first step taken is taking work posture data from data collection above consisting of 3 activities. Where this activity is uncertain but is often carried out by the respondent while doing work, divided into activities:

a. the wire wound activity for the solenoid carried out by squatting by the respondent,
b. the wire wound activity for the solenoid carried out by standing by the respondent,
c. the activity of winding the wire which is done by sitting.

Table 2 to Tabel 9 shows identification of the variances that occur using REBA:

Table 2. Neck Angle Identification

Step 1	**Activity (a)**	**Aktivity (b)**	**Activity (c)**
Neck Angle	>20^0	>20^0	>20^0
Skor	2	2	2

Table 3. Identification of Back Position

Step 2	**Activity (a)**	**Aktivity (b)**	**Activity (c)**
Back angle	20^0 - 60^0 flexion	upright	20^0 - 60^0 flexion
Skor	3	1	3

Table 4. Identification of Leg Position

Step 3	**Activity (a)**	**Aktivity (b)**	**Activity (c)**
Leg angle	Hitced up 30^0 - 60^0 +(1)	hitched up	hitched up
Skor	2	1	1

Tabel 5. Weigh Identification

Step 5	**Activity (a)**	**Aktivity (b)**	**Activity (c)**
weigh	<5kg	<5kg	<5kg
Skor	0	0	0

Tabel 6. Identification of Upper Arm

Step 7	**Activity (a)**	**Aktivity (b)**	**Activity (c)**
Upper arm angle	20^0 - 45^0 +(1) Rotated	20^0 flexion	20^0 flexion
Skor	3	1	1

Table 7. Identification of Forearms

Step 8	**Activity (a)**	**Aktivity (b)**	**Activity (c)**
Forearm Angle	>100^0 flexion	60^0 – 100^0 flexion	60^0 – 100^0 flexion
Skor	2	1	1

Table 8. Identification of Wrists

Step 9	**Activity (a)**	**Aktivity (b)**	**Activity (c)**
Wrist angle	15^0 extension +(1)	15^0 extension +(1)	15^0 extension +(1)
Skor	3	3	3

Tabel 9. Identification of Coupling

Step 11	**Activity (a)**	**Aktivity (b)**	**Activity (c)**
Coupling	Poor	Poor	Poor
Skor	2	2	2

4.5. Make a Variance Matrix

In making this matrix aims to find out the variance or problems that occur interrelated with each other during the transformation of the work process, this process is done by giving a score related to the variance that occurs to then determine the need for handling or do not need handling. By using the REBA taebl with the formula (Table Value A + Value Load = Value Score A), (Coupling Value + Table Value B = Value Score B), (Actifity Score + Table Value C = Value Score REBA). And get the following results:

Table 10. Matrix A

Table A	**Neck**												
		1				**2**				**3**			
	Legs	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Trunk Posture Score	**1**	1	2	3	4	1	2	3	4	3	3	5	6
	2	2	3	4	5	3	4	5	6	4	5	6	7
	3	2	4	5	6	4	5	6	7	5	6	7	8
	4	3	5	6	7	5	6	7	8	6	7	8	9
	5	4	6	7	8	6	7	8	9	7	8	9	9

Table 11. Matrix A Formulation

	Activity (a)	**Activity (b)**	**Activity (c)**
Table A	(2,2,3)	(2,1,1)	(2,1,3)
Scor	5	1	4

Table 12. Scoring A

Scor A	**Activity (a)**	**Activity (b)**	**Activity (c)**
Table A + Weighting	5+0	1+0	4+0
Scor	5	1	4

Table 13. Matrix B

Table B		**Lower Arm**					
		1			**2**		
	Wrist	**1**	**2**	**3**	**1**	**2**	**3**
Upper Arm Score	**1**	1	2	2	1	2	3
	2	1	2	3	2	3	4
	3	3	4	5	4	5	5
	4	4	5	5	5	6	7
	5	6	7	8	7	8	8
	6	7	8	8	8	9	9

Table 14. Matrix B Formulation

	Activity (a)	**Activity (b)**	**Activity (c)**
Table B	(2,3,3)	(1,3,1)	(1,3,1)
Scor	5	2	2

Tabel 15. Scoring B

Skor B	**Activity (a)**	**Activity (b)**	**Activity (c)**
Table B + *Coupling*	5+2	2+2	2+2
Scor	7	4	4

Table 16. Matrik C

Score A	**Table C**											
	Score B											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	1	1	1	2	3	3	4	5	6	7	7	7
2	1	2	2	3	4	4	5	6	6	7	7	8
3	2	3	3	3	4	5	6	7	7	8	8	8
4	3	4	4	4	5	6	7	8	8	9	9	9
5	4	4	4	5	6	7	8	8	9	9	9	9
6	6	6	6	7	8	8	9	9	10	10	10	10
7	7	7	7	8	9	9	9	10	10	11	11	11
8	8	8	8	9	10	10	10	10	10	11	11	11
9	9	9	9	10	10	10	11	11	11	12	12	12
10	10	10	10	11	11	11	11	12	12	12	12	12
11	11	11	11	11	12	12	12	12	12	12	12	12
12	12	12	12	12	12	12	12	12	12	12	12	12

Table 17. Matrix C Analysis

	Activity (a)	**Activity (b)**	**Activity (c)**
Table C	(5,7)	(4,1)	(4,4)
Scor	8	2	4

Tabel 18. REBA Analysis

Activity	**Rapid Eutire Body Assesment (REBA)**					
	Scor A	**Scor B**	**Scor C**	***Activity score***	***Final Score***	**Category**
(a)	5	7	8	1	9	High Risk
(b)	1	4	2	1	3	Low Risk
(c)	4	4	4	1	5	Medium Risk

4.6. Role Analysis of Personnel

Role Analysis of Personnel shown in Table 19.

Table 19. Role Analysis of Personnel

No	**Design**	**Quistioneir 1**	**Quistioneir 2**
1	heigh	Not high and not low	Reachable
2	material	iron	Alumunium
3	domension	to fit the solenoid	Lengthen to fit the solenoid
4	Opertation System	Semi Otomatis	Semi Otomatis
5	wide	Not too wide	to fit the solenoid
6	Long	Reachable	to fit the solenoid

4.7. Allocate Functions and Design Combinations

Specification of Design shown in Table 20.

Table 20. Specification of Design

No	**Design**	**Design spesification**
1	heigh	Reachable
2	material	Alumunium
3	domension	Lengthen to fit the solenoid
4	Opertation System	Semi Otomatis
5	wide	to fit the solenoid
6	Long	to fit the solenoid

4.8. Analyzing Perceptions and Responsibilities

From the design specifications by conducting interviews with the responsible respondents, namely the general chairman of the Semarang unissula robotics, the opinions identified from the design specifications were selected as a reference in the design of wire wound devices for solenoids.

The results of the interview found that the draft opinion specification 2 is a combined design that is chosen in the design of coil rolling machines for the robot solenoid to be used as a ball kicker, this

International Journal of Education, Science, Technology and Engineering, vol. 3, no. 2, pp. 35-47, December 2020. **DOI: 10.36079/lamintang.ijeste-0302.107**

combined design was chosen because the design specifications can be reached evenly, especially for members of Semarang unissula robotics itself and with a lightweight material that is aluminum so that the wire wound for solenoid which will be designed not too heavy and durable from rust is also not easy to porous.

4.9. Redesign and merge Subsystems

The anthropometric dimensions data needed in the design of a coil rolling machines for a solenoid are as follows Table 21.

Table 21. Antropometry Implementation

No	Antropometry	P5	P50
1	Elbow Height Stand (Tsb)	92.48	99.58
2	Hand Reach Forward (Jtd)	63.63	69.38
3	Shoulder Side Width (Lsb)	42.05	47.08
4	Maximum Palm Width (Ltm)	10.60	10.92
5	Palm Length (Ptt)	17.72	18.67

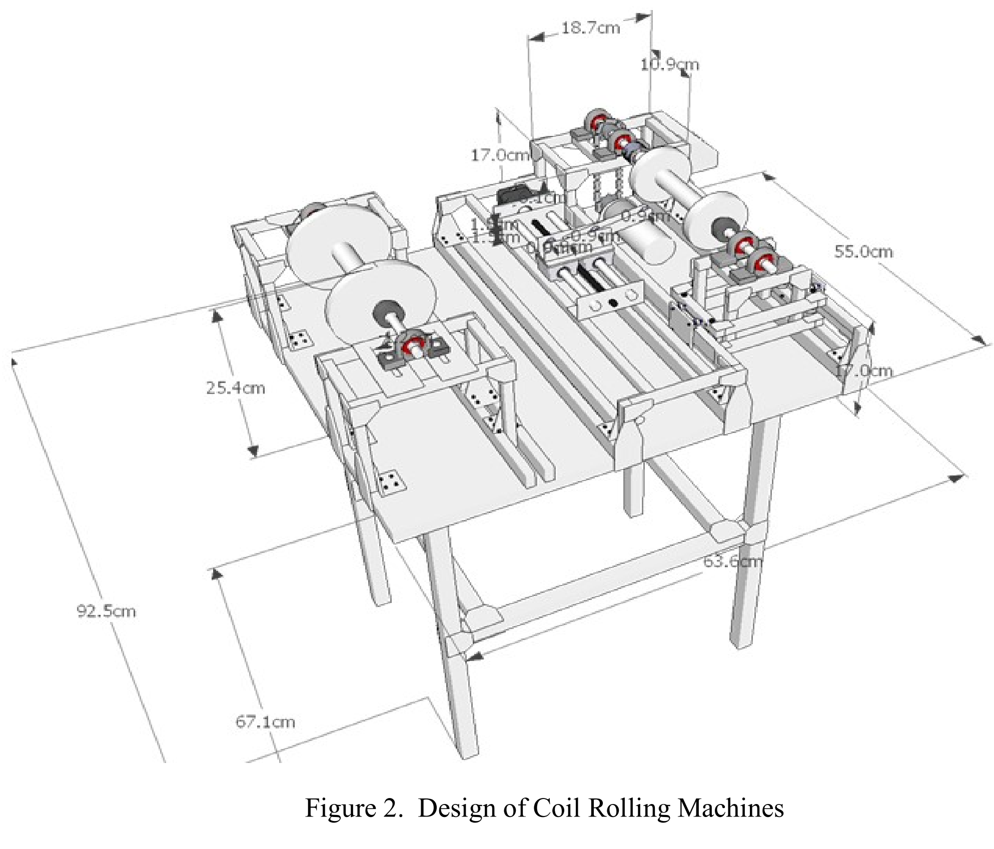

Figure 2. Design of Coil Rolling Machines

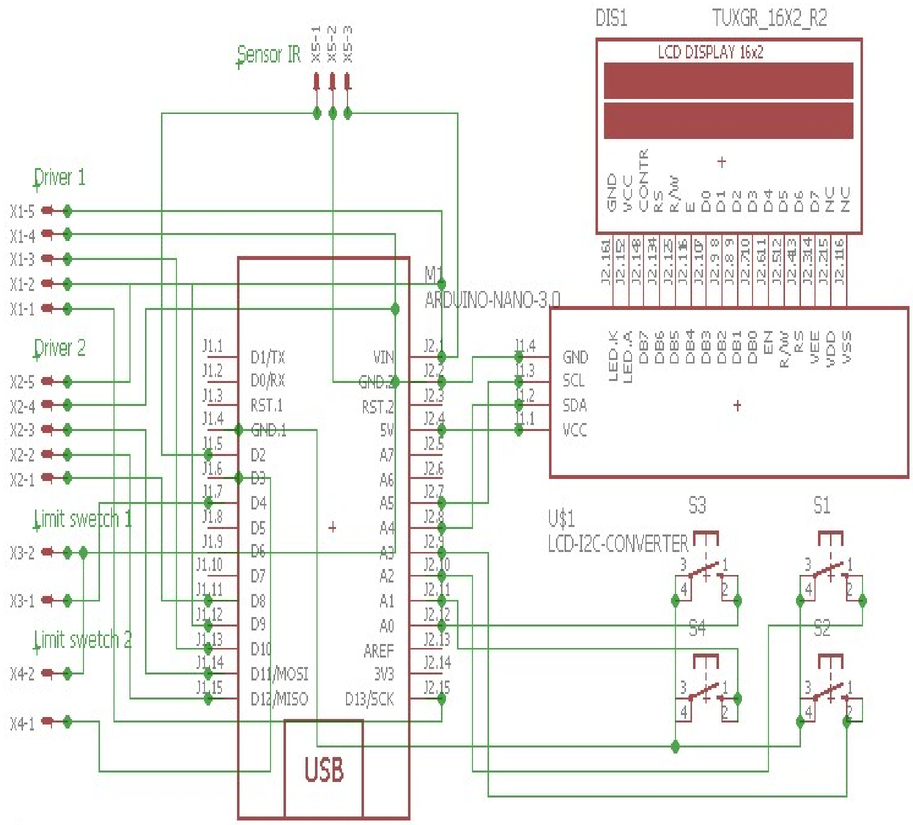

Figure 3. Microkontroler Design

4.10. Implement, Integrate and Improve Performance

At this last stage, namely the process of applying tools to work processes, with the aim to implement changes in work processes and work systems and observe the resulting performance improvements.

Figure 4. Tool Implementation

Table 22 shows a summary of the work processes of coil rolling after process improvement

Table 22. Summary of the Coil Rolling Process after Improvement

SUMMARY		
ACTIVITIES	**NUMBER**	**MINUTES (HOURS)**
○ Operation	10	387 minutes (6,45)
D Waiting	2	90 minutes (1,5)
□ Inspection	4	70 minutes (1,1)
Total	**17**	**547 minutes / 9,11 hours**

5. Discussion

There are several things to discusse comparation of work ergonomic factors and efficiency.

Table 23 compares system performance between before and after improvement.

Tabel 23. Comparison of Performance before and after Improvement

No	**Factors**	**Performance Conditions**	
		Before Improvement	**After Improvement**
1.	Ergonomics	The coil rolling process is not ergonomic	The coil rolling process is ergonomic
2.	Coil Rolling Machines	The Release process is done manually	The Release process is semi-automated
3.	Efficiency	The coil rolling process takes 720 minutes or 12 hours	The coil rolling process takes 547 minutes (9.11 hours) to reduce time of 173 minutes (2.8 hours)

6. Conclusions

Based on the results of the study, the following conclusions can be drawn:

1. Application of the Macro Ergonomic Analysis and Design (MEAD) method through the anthropometric approach using percentiles 5 and 50, we get the dimensions of the coil rolling machines that is the height of the tool from the height of the standing elbows (tsb) 92.5 cm, the width of the tool from the reach of the fore hand (jtd)) 63.6cm, length of the trapping device from the shoulder width (lsb) 55cm, the width of the tool movers from the maximum hand width (ltm) 18.7 cm and the length of the tool movers from the length of the palm (ptt) 10.9cm

2. The application of MEAD and REBA based on Arduino Microcontroller has resulted in the design of semi-automatic coil rolling machines to assist the ergonomic coil process that can reduce fatigue and muscle injury
3. The semi automatic coil rolling machines is able to reduce the time in the process of coil rolling to the seoloidoid of 173 minutes or 2.8 hours.

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