Palestine Polytechnic University

College of Engineering and Technology
Department of Mechanical Engineering

Automatic Car Washing Machine

By
Mohab Emer Amin Manna
Yazan Saleh

Project supervisor
Dr. Jasem Tamimi

Submitted to the College of Engineering in partial fulfillment of the requirements for the Bachelor degree in Mechanical Engineering

Hebron – Palestine
December (2019)

Palestine Polytechnic University

Collage of Engineering

Mechanical Engineering Department

Hebron – Palestine

Touchless car washing machine

By

Mohab Emer

Yazan Saleh

Amin Manna

Submitted to the Collage of Engineering

In partial fulfillment of the requirements for the

Bachelor degree in Mechanical Engineering.

Supervisor Signature

....

Department Head Signature

....

Jan. 2020

إهداء

بسم الله الرحمن الرحيم

(وقل اعملوا فسيرى الله عملكم ورسوله والمؤمنون) صدق الله العظيم
إلهي لا يطيب الليل إلا بشكرك ولا يطيب النهار إلى بطاعتك .. ولا تطيب اللحظات إلا بذكرك.. ولا تطيب الآخرة إلا بعفوك.. ولا تطيب الجنة إلا برؤيتك
الله جل جلاله
.. إلى من بلغ الرسالة وأدى الأمانة .. ونصح الأمة.. إلى نبي الرحمة ونور العالمين
سيدنا محمد صلى الله عليه وسلم

إلى من كلله الله بالهيبة والوقار.. إلى من علمني العطاء بدون انتظار.. إلى من أحمل أسمه بكل افتخار.. أرجو من الله أن يمد في عمرك لترى ثماراً قد حان قطافها بعد طول انتظار وستبقى كلماتك نجوم أهتدي بها اليوم وفي الغد وإلى الأبد.. والدي العزيز

إلى ملاكي في الحياة.. إلى معنى الحب وإلى معنى الحنان والتفاني.. إلى بسمة الحياة وسر الوجود
إلى من كان دعائها سر نجاحي وحنانها بلسم جراحي إلى أغلى الحبايب
أمي الحبيبة

.. إلى من بها أكبر وعليها أعتمد.. إلى شمعة متقدة تنير ظلمة حياتي
.. إلى من بوجودها أكتسب قوة ومحبة لا حدود لها
إلى من عرفت معها معنى الحياة
أختي

إلى أخي ورفيق دربي وهذه الحياة بدونك لا شيء.. معك أكون أنا وبدونك أكون مثل أي شيء.. في نهاية مشواري أريد أن أشكرك على مواقفك النبيلة ..إلى من تطلعت لنجاحي بنظرات الأمل
أخي

إلى الأخوة اللذين لم تلدهم أمي.. إلى من تحلّو بالإخاء وتميزوا بالوفاء والعطاء إلى ينابيع الصدق الصافي إلى من معهم سعدت ، وبرفقتهم في دروب الحياة الحلوة والحزينة سرت إلى من كانوا معي على طريق النجاح والخير
إلى من عرفت كيف أجدهم وعلموني أن لا أضيعهم
أصدقائي

Abstract

In this project we design an automated that included high-pressure, friction-free, water- and chemical-vehicle washing system is self-contained and has a lightweight aluminum frame that can be connected to a floor by adjustable leg supports, making it easy and fast to install into any self-service or automatic car wash bay. The system is operated by high air pressure and the washing spray head is adjustable in perpendicular directions enabling the spray head to scan for any possible spot within the machine's own boundaries. Photo-electric infra-red rays senses the existence of the vehicles being washed; ultrasonic signals are sent to a programmable controller and directs the spray head to look for the dimensions of different sized vehicles. The system maintains a secure but efficient washing distance between the spray head and the vehicle surface after the vehicle dimensions are determined by contact between the sensors and the programmable controller. A system is provided for indexing the spray head, which allows the spray head to rotate exactly ninety degrees for each corner of the vehicle.

في هذا المشروع تم تصميم نظام اوتوماتيكي يتضمن نظام عالي الضغط، بدون احتكاك، وباستعمال الماء والكيماويات، وهو مستقل بذاته وله إطار ألومنيوم خفيف الوزن يمكن تثبيته على الأرض بواسطة دعامات الأرجل القابلة للتعديل، مما يسمح بتثبيته بسهولة واستخدامه في محطات غسيل السيارات الاوتوماتيكية التي تعمل بالخدمة الذاتية. يتم تشغيل الجهاز بضغط هواء مرتفع نسبياً ورأس غسيل الرش متحرك في اتجاهات عمودية مما يسمح لرأس الرش بالبحث عن أي موقع ممكن داخل حدود الماكينة نفسها. ترسل حساسات الأمواج فوق الصوتية إشارات لتدل على وجود السيارة التي يتم غسلها؛ ترحل الإشارات إلى وحدة تحكم قابلة للبرمجة ويتم توجيه رأس الرش للبحث عن أبعاد المركبات ذات الأحجام المختلفة. بمجرد تحديد أبعاد السيارة عبر الاتصال بين الحساسات ووحدة التحكم القابلة للبرمجة، تحافظ الماكينة على مسافة غسل آمنة وفعالة بين رأس الرش وسطح السيارة. يتم توفير آلية لتوجيه رأس الرش الذي يجعله يدور تسعين درجة في كل زاوية من زوايا السيارة.

Table of contents

List of figures

List of tables

1. Introduction

Car wash is a facility used to clean the exterior and, in some cases, the interior of vehicles. It can be done automatically or manually. The automatic method is faster and more comfortable, while the manual method requires the use of a soap, gloves, buckets and plenty of water, but automatic method only requires placing the car in a car wash. Also, it takes only five to ten minutes, which is much less than the time required in the manual method. In simple words, car wash is the act of cleaning vehicles, since human tends to live in a clean environment, it can be said that car wash began since the advent of cars in the late nineteenth century, since then it has grown to become a multi-million-dollar industry.

In the early 1900s, the manual car washing was a pioneer and it required a great effort of men to complete this process. However, in this period there an urgent need to develop a tool for washing cars [1].

In 1946, the first semi-automatic car wash was operated using an automated pulley system and then manually washed. A lot of development happened to the carwash industry in 1955. Dan Hanna opened a first automated car wash (Rub-a-Dub) in Oregon-united states. By 1957, Hanna Enterprises had thirty-one carwashes in American, Figures (1-1) and (1-2) shows [2].

Figure1 -1Wwashing car by rolling in 1950s [4]

Figure 1-2 Washing car by high pressure water in 1950s[4]

However, in 70’s the car washing industry was not developed as expected due to the drop of sailing of car in USA. But, in 80's this industry was re-development since the sailing of car was increased. Australia was also seeing big success with car washes. By the end of the 80’s there were automated car washes in 56 countries including Australia. [3]

Recently, the global boom in car washing has taken place with the development and expansion of technology, the Hanna Enterprises now (Hanna-Sherman International) biggest global car washing factory in the world, Figures (1-3) and (1-4) shows. [3]

Figure 1-3 Washing car by high pressure water in 2000s[5]

Figure1-4 Washing car by rolling in 2000s[6]

1.1 Methods of car washing

Car wash has many conventional methods. The most important of these methods can be summarize methods as:

-Hand wash methods; in this method, the cars are washed manually by the human labor, but as any manual method, the disadvantage of this it is a time consuming, and the end results depends on the human labor efficiency, Figure (1-5) shows.

Figure 1-5 Traditional washing car [7]

-Rolling method; in this method, a machine uses rolls to wash the car, the rolls are moved forward and backward on the body of the cars, but it is found that it causes scratches in the body of car, Figure (1-6) shows.

Figure1-6 Rolling car washing machine [8]

-Chemical car wash; in this method, chemicals are used with no water. However, the main disadvantage of this method that it can affect the paint of car, Figure (1-7) shows.

Figure 1-7 Chemical car washing machine [9]

-Steam car washes; in this method, steam jet and fiber towels are used, but, in some cases it can cause harm to the control system, the electronic engine, and the car's ignition system, Figure (1-8) shows.

Figure 1-8 Steam car washing machine [9]

2. Working principle of car washing machine

2.1 Introduction

Taking into account the disadvantages of existing car washing methods (at section 1.1), the new developed tool of a car-washing system is size of the ground that need.. In this project, we design a system that accomplish the needed task effectively and economically. To do this, we suggest a car-washing system to overcome the problems of the commonly used systems.

2.2 Project idea and advantages

The idea of project is to design and implement an automated Arduino controlled machine that wash the car by an automatic method.

This idea has many advantages compared to traditional methods including: Reduce the effort and number of workers, more accurate than traditional method, and increase the quality of washing, ensure safety and health for workers and save the time space, water consumption and electric consumption that needed for washing the car.

2.3 Project Objectives

1-To build an automated machine for car-washing without touch the car.

2-To develop a used technology with less cost.

3-To increase the quality of washing cars with high features.

2.4 Recognition of the need

2.4.1 Quality of car washing machine

In the local market and other markets, there is a need for production of a machine that provides high quality of washing the cars, this means, the machine must provide the cleanliness and maintain the water and the electrical consumption. In addition, the machine must reduce the time, space and effort that needed to do the same work.

The suggested machine must have the following features:

Friendliness use, High safety factor, easy to maintenance, simple working mechanism and environment friendly.

2.5 Machine Working Mechanism

In our project we will show the new technology in washing cars using fully automated machine controlled with Arduino. This car wash method guarantees less water and electricity consumption, and is more accurate for washing.

In order to know the proposed machine, we shall identify how the machine works and how the processing stages pass through it to get washed-car final. Car-washing processes can be divided into two stages:

1) homing the car in the machine house.

2) Starting the machine, and washing the car.

2.5.1 Homing the car in the car-washing house.

In this stage, the driver drives the car to the washing place and push the bottom that start the machine, the machine will not start unless the cost of the washing is guaranteed Figure (2-1) shows.

Figure 2 -1 Car position in the machine [10]

2.5.2 Starting washing.

When the driver drives into machine, a sensor checks if it is in the right place or not. After paying for the service, the customer must push the starting button.

Firstly, when the machine starts, the sensor measures the size of the car and gives the reading to the Arduino and sends the message to the motors to take the safe distance between the car and the machine arm. Then finally the machine washes the vehicle in the following order (High pressure pre-wash for under chassis and wheels, smart 360° rotate, flush car body 360° and spray various washing liquid, high-precision proportioning technology, soft water with crystal wax coat, unique embedded fast drying system).

Step 1: High pressure pre-wash, water is pumped through a nozzle for under chassis, body sides and wheels to remove dirt, Figure (2.2) shows.

Figure 2-2 High pressure wash for under chassis and wheels[10]

Step 2: The smart 360° arm is rotated by controller around the car to be sprayed by water and washing liquids from a nozzle fixed on the arm to achieve the sufficient pressure. The full rotation is done within less than a minute, which saves water and electricity by 50% and 60% respectively. Figure (2.3) shows.

Figure 2-3 Sprayed water by smart 360° rotate arm[10]

Step 3: Special chemicals are sprayed from an upper nozzle on the vehicle to dissolve stuck dirt and oils. Only sufficient amounts of chemicals are used, which makes it costly efficient. Figure (2.4) shows.

Figure 2-4 High precision proportioning technology[10]

Step 4: Magic color thick shampoo is applied on the body so the cleaning maintenance component contact with dirt, thereby improving the efficiency of decontamination of dirt, which moisturize the paint colors and gives a shiny luster, the used technology is non-corrosive for the car paint. Figure (2.5) shows.

Figure 2-5 Magic color thick shampoo[10]

Step 5: Soft water with crystal wax coat is applied on the car, which gives a shiny gloss and better look for the car paint. This coat also provide protection for the paint against acid rain, pollution and erosion. Figure (2.6) shows.

Figure 2-6 Soft water with crystal wax coat [10]

Step 6: The vehicle is dried with a unique embedded fast drying system composed of high-speed air fan motors to be able to effectively finish the drying process in short time with least power consumption. Figure (2.7) shows.

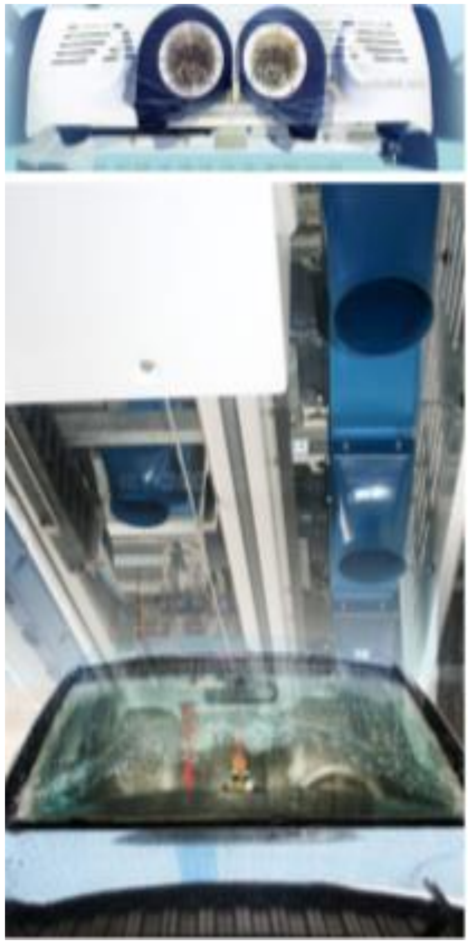


Figure 2-7 Unique embedded fast drying system[10]

3. Mechanical Design

3.1 Requirements

1- Five to Six minutes are needed to complete the cleaning process.

2-The machine is 3350 mm high ,3850 mm wide, and 7600mm long.

3-Max Allowed car size to be used (length=5900mm, width=2090mm, and height=2050mm).

4-The body of machine is made from stainless steel, but the piston pump is made from copper.

5-Water consumption in the system is 50% less than traditional washing methods.

6-Electrical consumption in the system is 60% less than traditional washing methods.

7-Automatic and manual modes can be used to run the system.

3.2 Conceptual Design

When the driver drives the car at a specific place in which the machine that equipped with a unique chassis and fan hub flush function, eighty bar high pressure water effectively removes dirt on chassis, body sides and wheels. Figure (3-1) shows.

Then, the car stops at particular place, in this place the process of washing the car is done, then a smart arm rotates the car 360° so the car body is flushed 360°e and sprayed with various washing liquids. The machine can Complete 360° rotation within 28 seconds, 50% water saving50%, and 60% electricity saving. Length and width of vehicles are automatically detected. Up to 85 bar high pressure water is used, which can easily remove the dirt. Only [twenty-fifty] mL magic color thick car shampoo is used for washing one car through high precision liquid proportioning system.

Secondly, machine is use high-precision proportioning technology, was only [twenty-fifty] mL soap consumption for washing one car through high precision liquid proportioning system, save material and cost efficient.

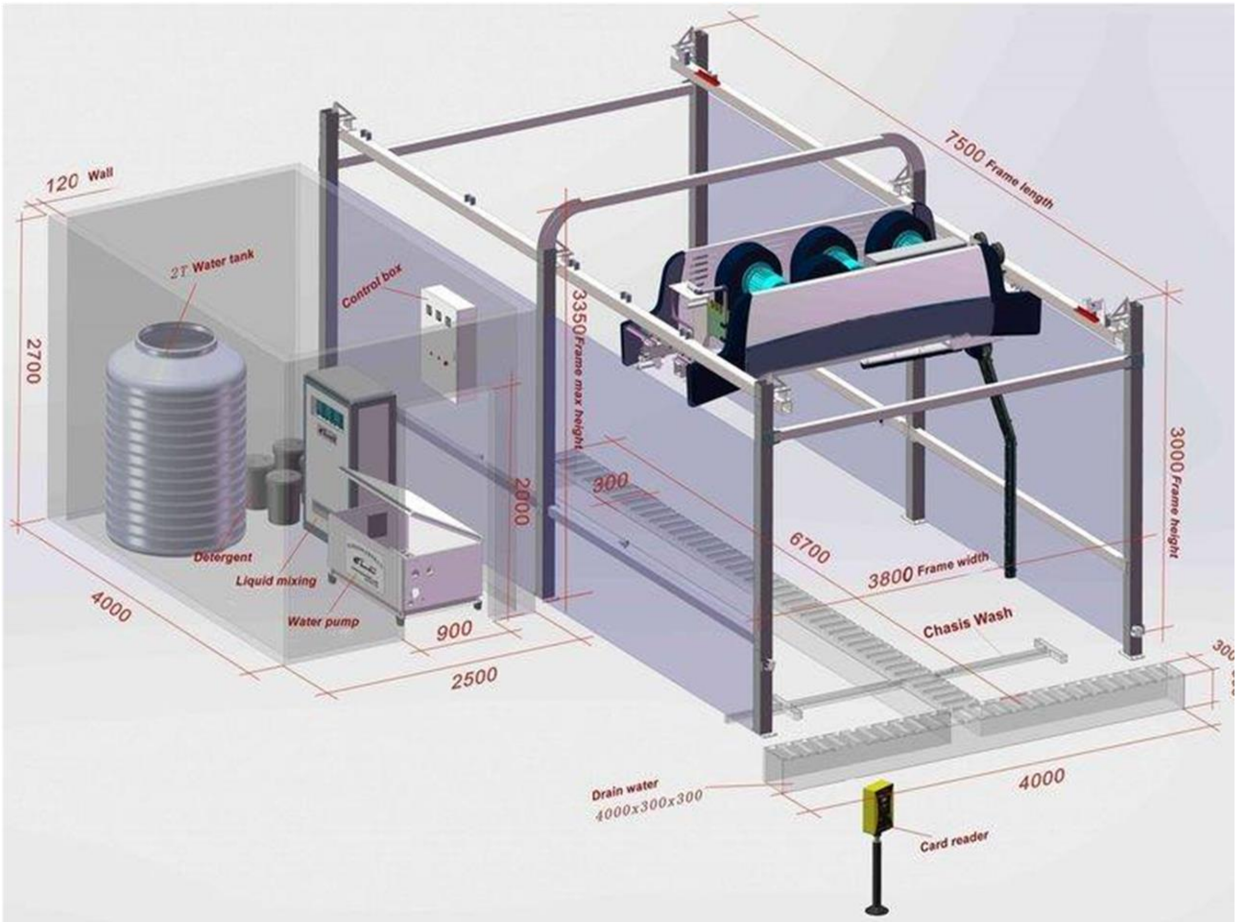


Figure 3-1 The dimension of machine [11]

3.3 Contents of car washing machine.

As mentioned previously, the car washing machine consists of three components, we will now go in details of this components.

3.3.1 Frame

The job of main frame is carrying all parts of the machine: motors, gears, arm and bearing Figure (3-2) and Table (3-1) shows.

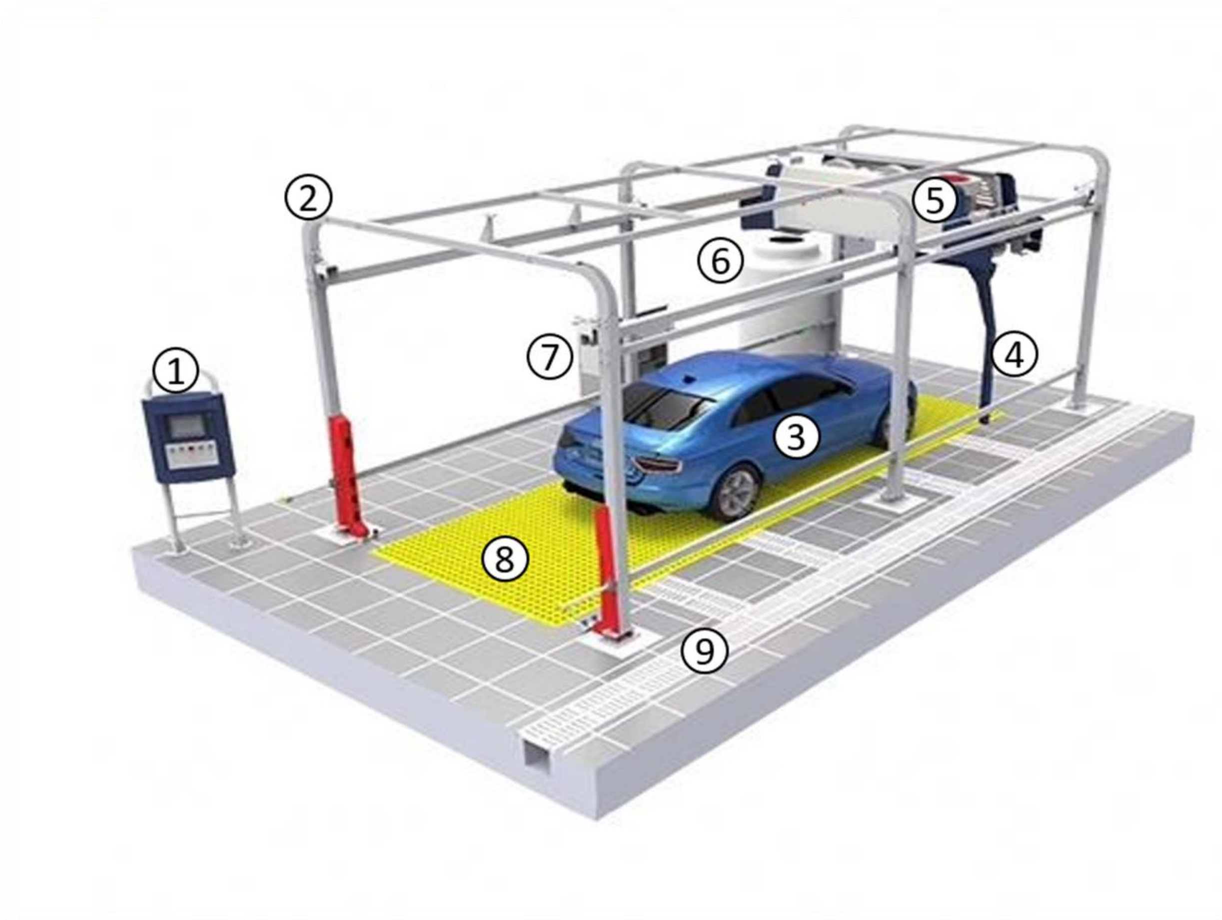


Figure 3-2 mechanical design[12]

Table 3 -1 Name of components

1	2	3	4	5	6	7	8	9
push button(Start)	Fram	The car	Arm	Body of machine	Tank of water	Box of wax	Car position	Sewage drainage

3.3.2 Arm

The mechanical L shape arm is one of the main parts of the machine. It carries some of the neatly arranged nozzles spray, which gives the required pressure for pushing water and soap. The arm allows the nozzles spray to rotate at 360° degrees and cover all parts. Figure (3-3) shows.

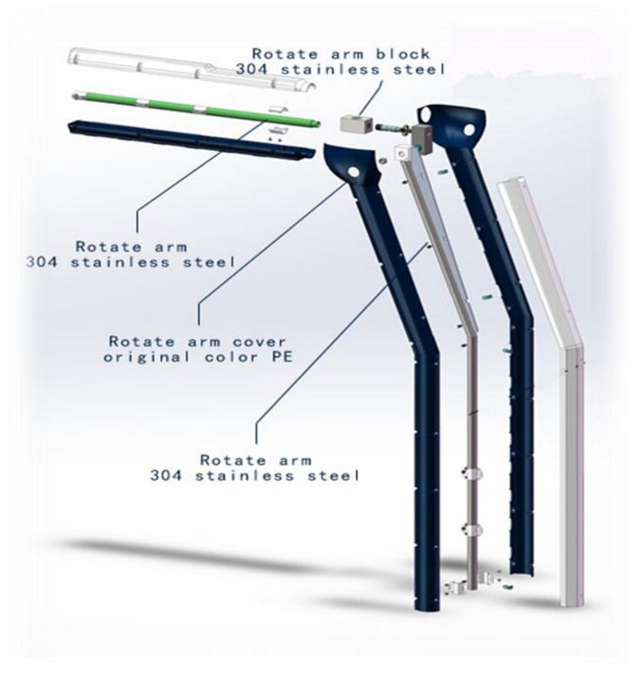


Figure 3-3 Mechanical L shape of arm [11]

3.3.3 Nozzle spray

A spray nozzle is a precision device that facilitates dispersion of liquid into a spray. Nozzles are used for three purposes: to distribute a liquid over an area, to increase liquid surface area, and to create impact force on a solid surface. Figure (3-4) shows.

Figure 3-4 Spray nozzle [13]

3.3.4 Main shaft

The main shaft serves as the holder wheel. The main shaft has a circular shape in the position of wheels' holder, a groove along the shaft, and special position for main bearings.

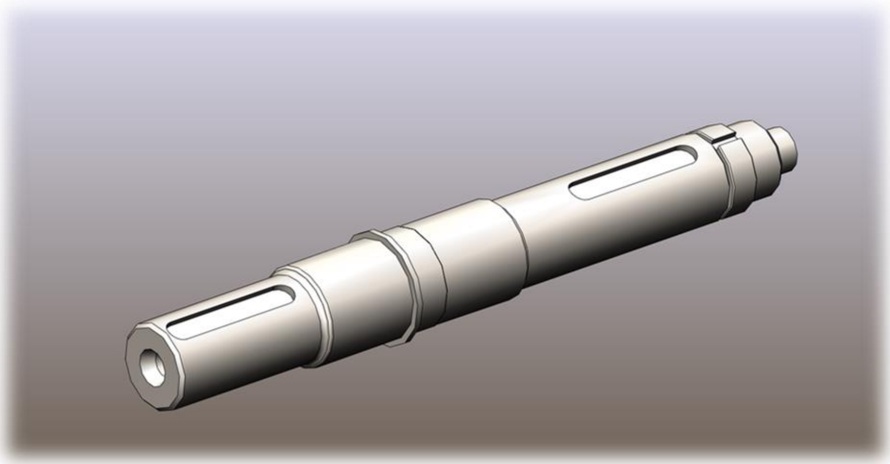


Figure 3-5 The main shaft of wheels [14]

3.3.5 Transmission System

3.3.5.1 Wheels

Caster heels are being used to carry on the machine's body and move it at both directions on a base frame.

Figure 3-6 Slider wheels of axis motion [15]

3.3.5.2 Bearing

Bearing are used in the wheels into the shaft of the machine permit the rotational motion of the shaft without affecting the wheels or the frame as Figure (3-7) shows. Dimension of bearing in Appendix A in Section (3.4.3 and 3.4.4), page (45 and 46).

Figure 3-7 Bearing of wheels [16]

3.3.5.3 Pulleys

The rounded moving parts of the machine which responsible to the movement process of the machine, it's existing at both sides of the belt, motor side and the machine side. Figure (3-8) shows

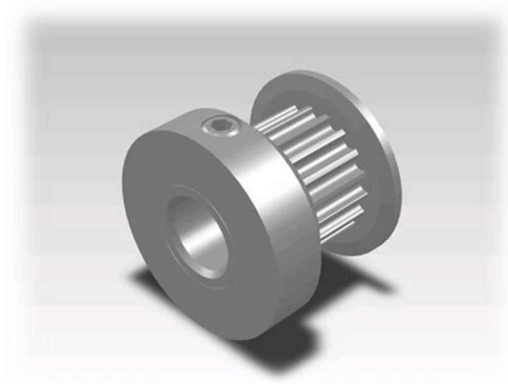


Figure 3-8 Pulleys for transmit motion form motors [17]

3.3.5.4 The belt

Transferring the movement power from the motor to the machine depends on the existence of a belt, which is connected to some pulleys from the motor side to the machine side. Type of belt is dryer drive .

Figure 3-9 The belt that transmit motion from pulleys to the wheels [18]

3.4 Table of Results

All the computational results required for this machine are summarized in the table (3-7) below, taking into account that the calculations and equations used to obtain these results are present in the appendixes.

Table 3-2 table of results

Sections	Required	Result	Unit
A1 Page 42	Mass of body machine	500	kg
	Weight of body machine	5000	N
	Forces act on columns ($F_A = F_B = F_C = F_D = F_E = F_F$)	833.3	N
A2 Page 43	Moment in the beam (M)	3.1248	kN.m
	The reaction force in the two sides of shaft (R1, R2)	833.3	N
	Length of beam (L)	3.75	m
	Maximum allowed deflection (y_{max})	-8*10^{-3}	m
	Dimension (a)	0.25	mm
	Dimension (b)	0.25	mm
	Bending stress on the longitudinal beam (σ_b)	21.6014	ksi
A3 Page 45	Longitudinal Force (F_x)	1.47	kN
	Vertical Force (F_y)	0.833	kN
	Radial load on the bearing (F_r)	1.528	kN
	catalog rating (C_{10})	13.2	--
	shear stress (τ)	$55 * 10^6$	Mpa
	Factor of safety of bearing (n)	4	--
	Inner diameter of bearing (d)	9.3	--
	Bearing dimension	------	
	Calculating data of bearing		

	Mass bearing (m)	0. 35	Gram
A4 **Page 53**	Force on each bolt in frame (P)	0.333	KN
	Stiffness for each Bolt (k_b)	466.8	MN/n
	Member stiffness (k_m)	1379	MN/m
	Stiffness constant of the joint (C)	0.253	--
	Bearing in bolt loaded (F)	296	kN
A5 **Page 53**	Bearing in member (F)	188.01	kN
A6 **Page 54**	Force of shear between two members (F)	400	kN
A7 **Page 54**	Force of shear of member (F)	91.256	kN
A8 **Page 55**	Force of tensile yield (F)	472	kN
	Force of member yield (F)	370.34	kN
A9 **Page 55**	buckling force (F)	3.788	kN
A10 **Page 57**	acceleration of the belt (a)	0.571428	m/s^2
	angular acceleration of the belt ($\ddot{\theta}$)	1.27	rev
A11 **Page 59**	The motors torque(T)	789.4	N.M
A12 **Page 60**	Velocity of the fluid through the outlet(V)	80	m/s
	Change in pressure(ΔP)	3197.5	Pa
	Flow rate of the fluid(Q)	0.015	m3/s
	TL (torque of shaft servo motor)	0.0023	N.m

4.Electrical Design

4.1 Introduction

This chapter shows how to select the electrical components that will be used in the project, Generally, Figure (4-1) shows the hardware components that will be used in the project and interaction between them.

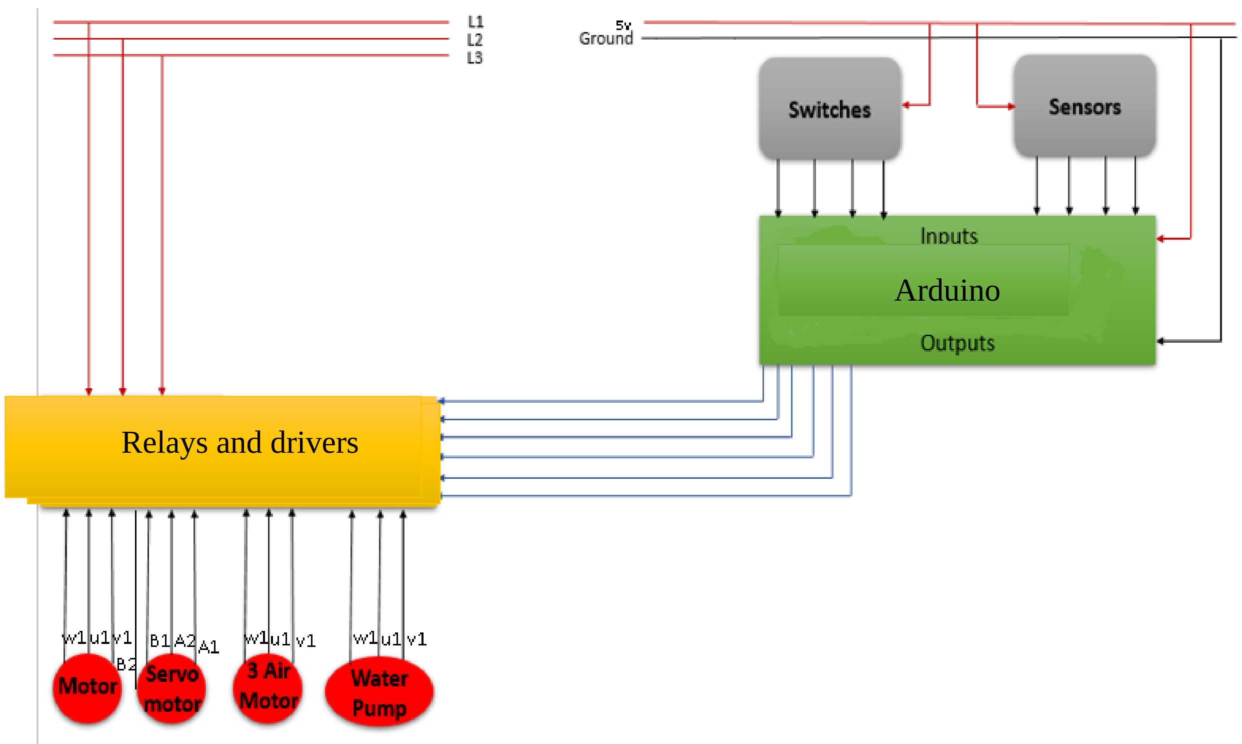


Figure 4-1 Hardware component

In the following, we explain the functions of each part and what role does it play in the overall project.

4.2 Electrical motor

The speed of the electrical motor always depends on the properties of the electrical signals (voltage and frequency) that comes from drivers which are connected to the controller. It is used to transfer the motion to the belt to the pulleys to rotate forward or reverse. Thus, the pulleys transfer the motion from the belt as Figure (4-2) shows.

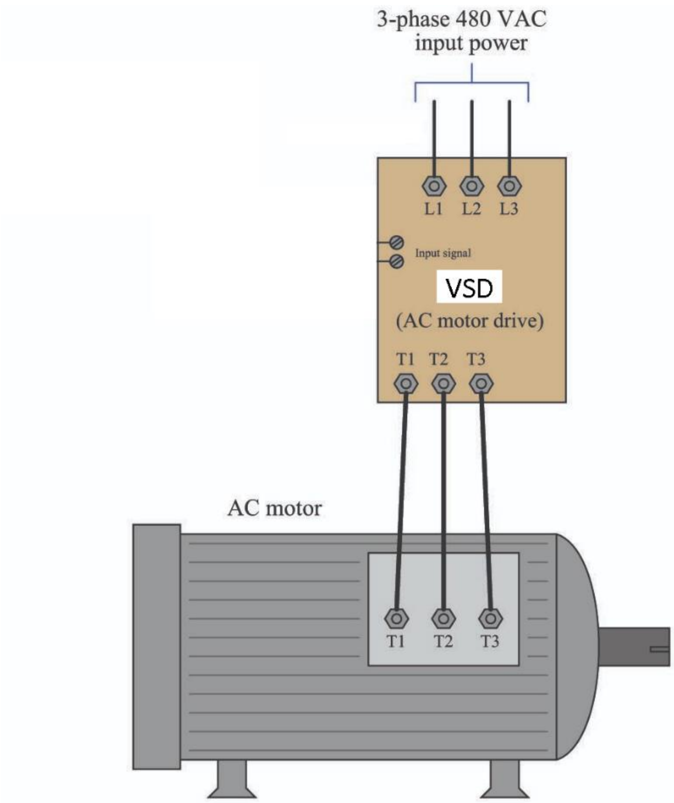


Figure 4-2 Schematic AC electrical motor [19]

In this project, we will use a three-phase AC motor, Table (4-1) shows the nameplate information of the used motor and its specifications, which is selected based on torque needed to transmit the applied load calculated in chapter 3.

Table 4-1 Nameplate of ac motor

Voltage	380 V
Power	5.36 hp
Speed	500 rpm

4.3 Air fan motor

Air fan motor pumps the air quickly enough to dry the car after washing in a short period of time.

Table (4-2) shows the nameplate information of motor.

Table 4-2 Nameplate of air fan motor

Voltage	380V
Power	2.6 kW
Air flow rate	6.3m3/sec
Frequency	50 Hz

4.4 Servo motor

It is a rotary_actuator or linear_actuator that allows for precise control of angular or linear position, velocity and acceleration.

We will use it to rotate the arm around the car by (90°) angle in each corner of the car as Figure (4-3) shows.

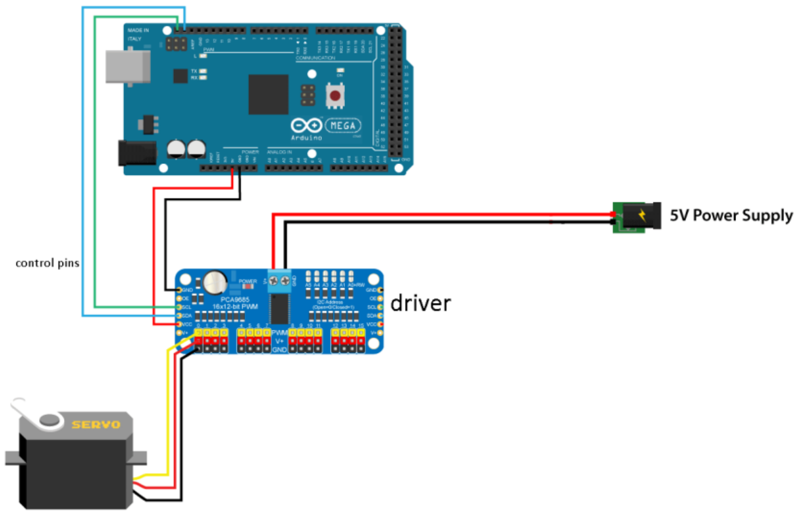


Figure 4-3 Schematic of servo motor with Arduino controller [21]

By use servo motor, Table (4-3) shows the nameplate information of the used motor and its specifications, which is selected based on torque needed to transmit the applied load calculated in Appendix A.

Table 4-3 Nameplate of servo motor

Voltage	220V
Power	1hp
Speed	3000 rpm
Frequency	50 Hz

4.5 Water pump

We use high pressure water pump to get appropriate pressure that will clean the car and remove all stains and dirt as Figure (4-4) shows.

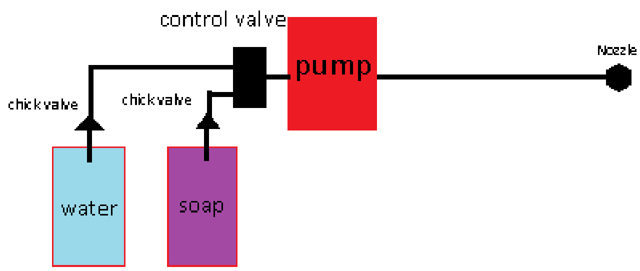


Figure 4-4 Schematic of Pump [21]

Table (4-4) shows the nameplate information of motor that we choose it by depend on the pressure that enough to remove all stains and dirt.

Table 4-4 nameplate of pump motor

Voltage	380 V
Power	5 hp
Max Head	186 m
Frequency	50 Hz
Speed	2950 rpm

4.6 Variable Speed Driver

A variable speed drive (VSD) as shown figure (4.6). Also known as a frequency converter, adjustable speed drive or inverter, is an electronic device that controls the characteristics of an electrical supply of a motor. Therefore, it is able to control the speed of motor, achieving a better match with the process requirements of the machine.

A VDS works by converting the incoming electrical supply of fixed frequency into a variable frequency output. This variation in frequency allows the drive to control the way in which the motor operates a low frequency for a slow speed, and a higher frequency for a faster speed. The output can also be changed to enable the motor to generate more or less torque as required. So, the motor and drive combination might be used for turning a large load at fairly slow speed, or turning a lighter load at high speeds maximizing efficiency [23]. When considering fitting VDS to a motor, there are a number of issues to consider:

1-Type of torque

2-Size required

3-Type of control needed

Figure (4-5) shows the typical connection of the driver.

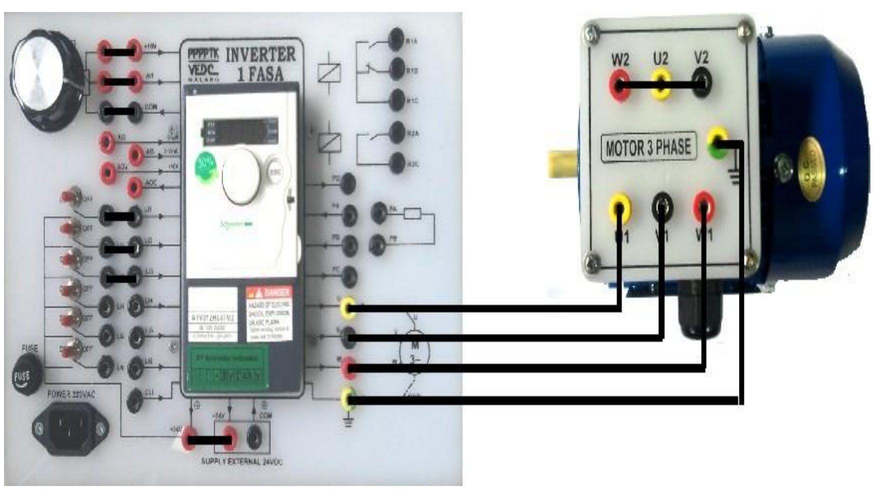


Figure 4-5 Typical connection of driver

4.7 Contactor

It is an electrically controlled switch used for switching an electrical power circuit, similar to a relay except with higher current ratings and a few other differences.

4.8 Thermal Relay (Overload)

It is a protector that uses the thermal effect of current to cut off the circuit. When the thermal relay is used for overload protection in the motor, it often works with ac contactor to form an electromagnetic starter, and then to be used in the control and protection circuit of the three-phase asynchronous motor[26.

Figure (4-6) shows the typical connection of the contactor and Thermal Relay.

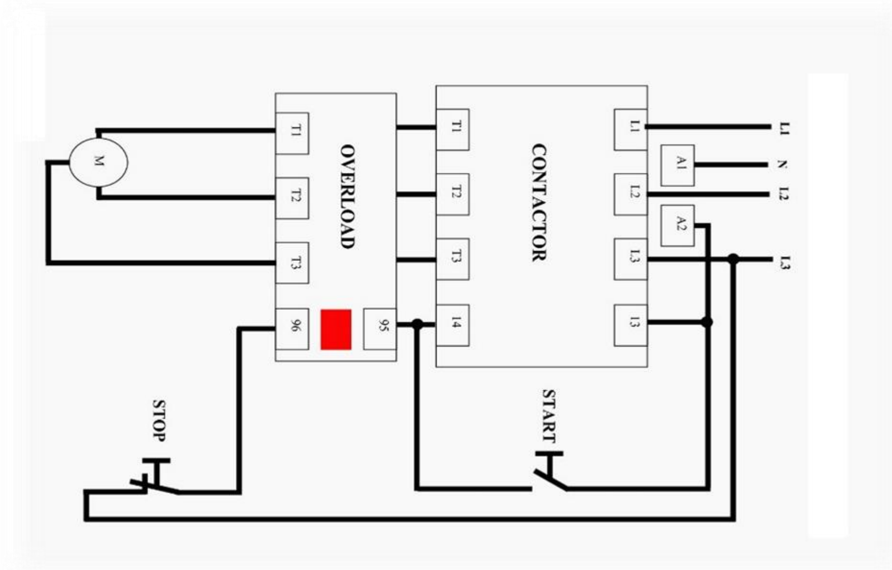


Figure 4-6 Typical connection of the contactor

4.9 Phase Sequence Protection Relay

It is an electronic changeover type relay, which provide normally open or normally closed type output, when the correct phase sequence of a three-phase system is interrupted. They are widely used in three phase power monitoring applications, where we have to monitor and control the raw power supplied from the source. To understand the insight of a phase sequence relay**.**

Maintaining the correct phase sequence is very important. Conventionally, the RYB phase sequence is called as positive phase sequence. Major industrial loads such as three phase induction or synchronous motors are connected in positive phase sequence with the supply. However, if the phase sequence is reversed from the supply side, that is “BYR” instead of “RYB”, then the motor will start rotating in reverse direction [23].

Phase Sequence Protection Relay as Figure (4-7) shows.

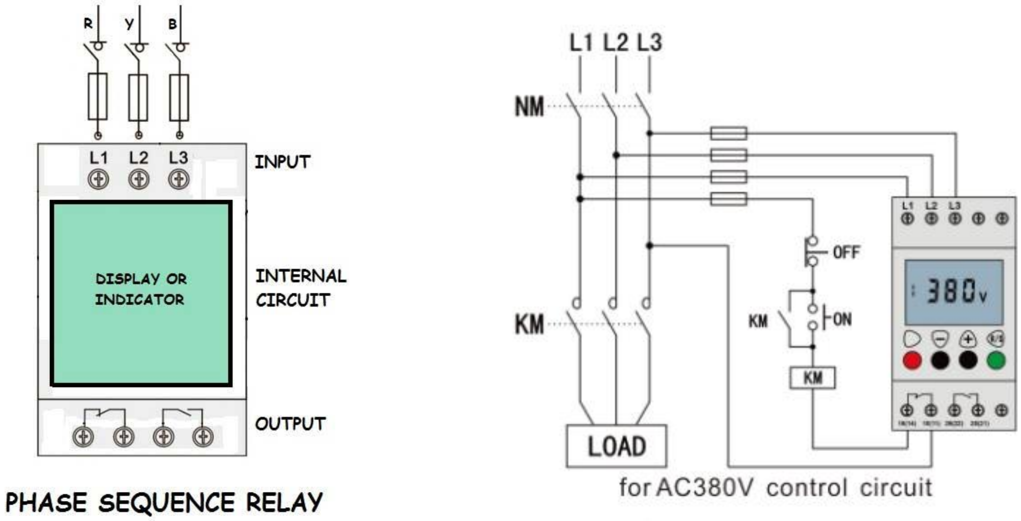


Figure 4-7 Phase Sequence Protection Relay

4.10 Ultrasonic Sensor

Ultrasonic sensors are characterized by their reliability and outstanding versatility. ultrasonic sensors can be used to solve even the most complex tasks involving object detection or level measurement with millimeter precision, because their measuring method works reliably under almost all conditions [28].

by use it to detect the distance between the car and the nozzles, to take the safety distance; that will not cause scratch in body of car. Ultrasonic Sensor as Figure (4-8) shows.

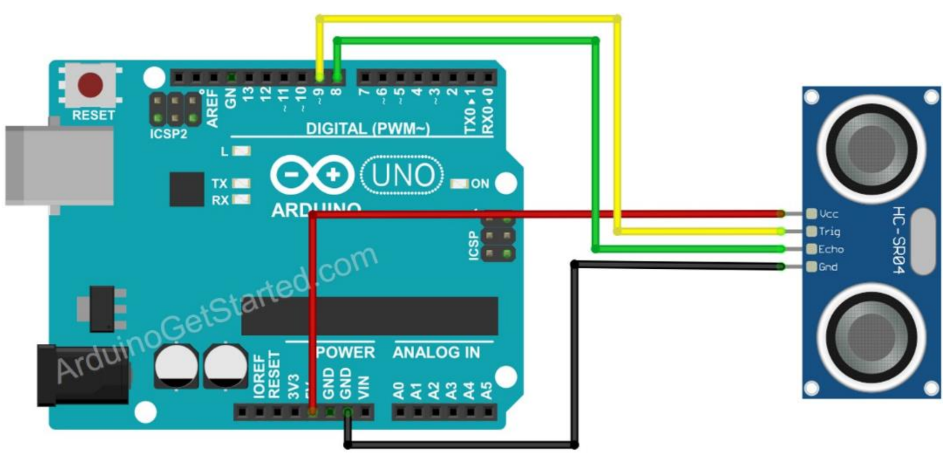


Figure 4-8 Schematic of ultrasonic sensor [29]

4.11 Limit switch

Limit switch is a switch operated by the motion of a machine part or presence of an object. They are used for control of a machine.

In our project there are two limit switches, one to check the level of water in the tank of water and another to check the chemical in the tank of chemical. Limit switch as shown as in Figure (4-9)[30].

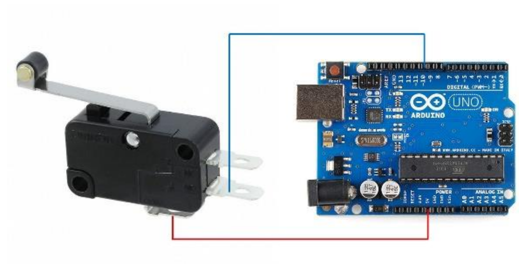


Figure 4-9 Limit switch and Arduino circuit

4.12 Electrical circuit

The following Figure (4-10) shows the electrical circuit of the machine system.

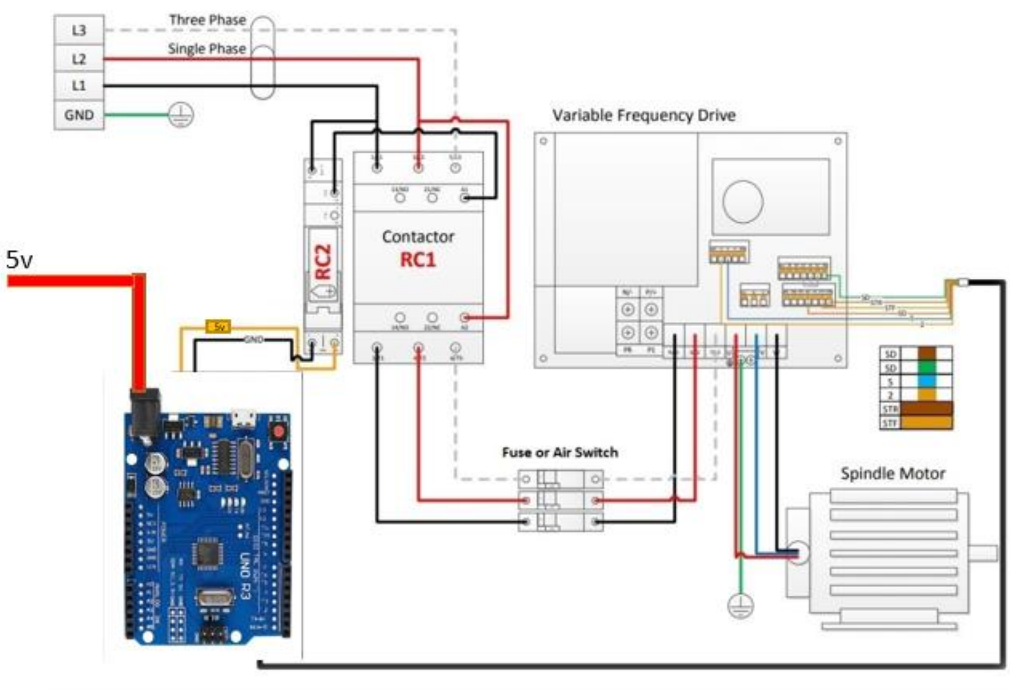


Figure 4-10 Electrical circuit

5.Control Design

5.1 Introduction

The controller acts as the brain of the machine system. All parts (electrical and mechanical) of the controller are integrated together to serve the machine task of the controller which is to receive digital signals; a signal that represents a sequence of discrete values, from a computer and translate these signals into mechanical motion through motor drivers.

This chapter shows the controller design and the software program which will be used to control the movement of the actuators.

Open loop control system will be used to control the machine since we use stepper motors.

5.2 Closed loop control system

Closed loop system in Figure (5-1) is a type of continuous control system in which the output has influence of effect on the control action of the input signal. In other words, in a closed loop control system, the output is measured and feedback for comparison with the input. Therefore, the output signal nautically follows the input with feedback signal.

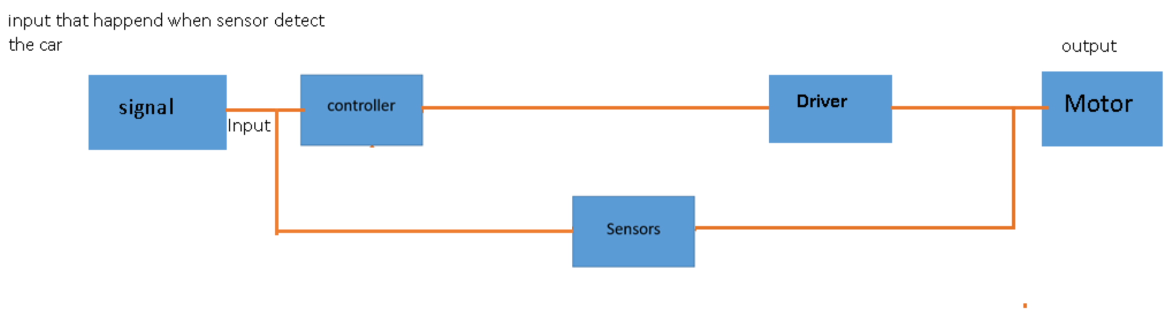


Figure 5-1 Closed loop control system

In the closed loop control system, the controller receives the order from sensors before the controller creates the necessary motion and direction signals to perform the desired task and sent it to the motor driver. The driver leads the motor to rotate.

The driving and controlling system include two AC motors and servo motor for driving a washing machine for washing a car and a controller between the motor and a power system to control power to be supplied to the motor.

5.3 Arduino controller program

To inference with the output and input the address of each part must be known and named in the software.

Figure (5-2) shows the program of microcontroller, can receive the desired commands from the computer. The microcontroller converts these commands to electrical signals, these signals are sent by microcontroller to the motor drivers which moves the motors.

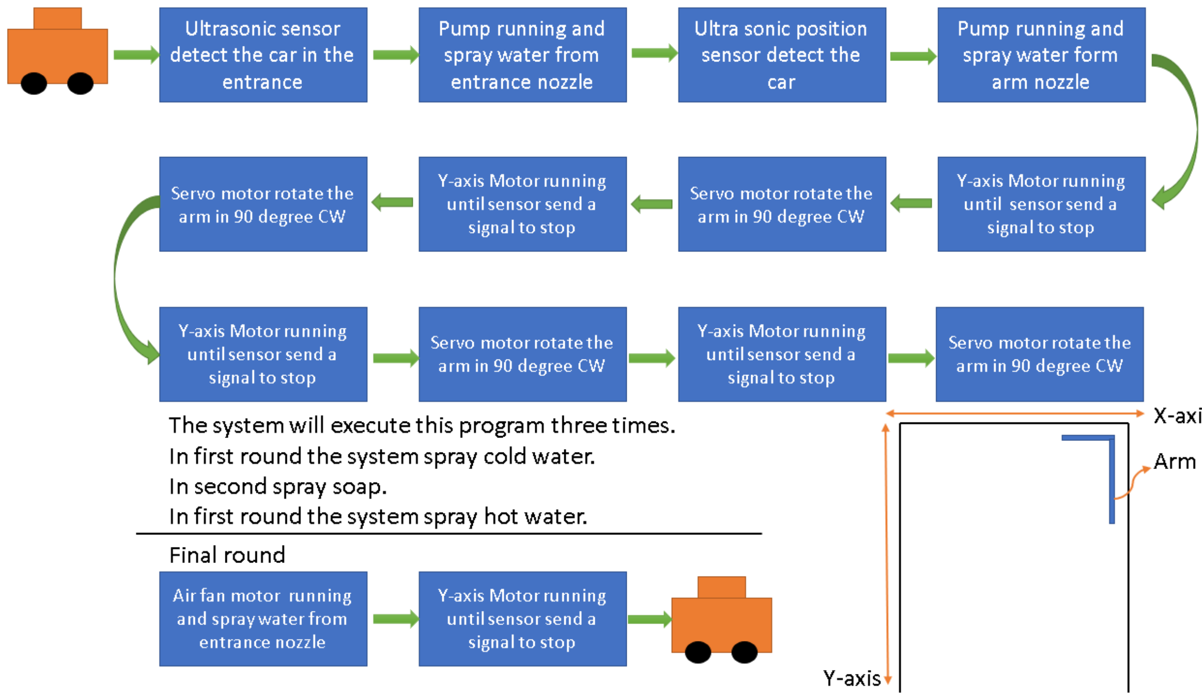


Figure 5-2 Flow chart of machine program

6.Manufacturing and assembling

This chapter explains the process of machine setup that is used in the project. Five steps are used to build this machine; cutting, welding, drilling, finishing, and coating. In the following, we explain each process for each part of the machine.

6.1 Main frame:

Three steps are followed to build main frame. First, cutting the sheet steel with the scale dimensions, then welding the cut sheet based on the scaled shape, finally, cleaning and coating it. figure (6-1) shows the main frame in the coating process.

Figure 6-1 Frame

6.2 Bearing and Axis

Three steps are followed to build x-axis and y-axis motion system. Running aluminum plate with the scale dimensions using cutter machine, finishing and drilling them to be fixed with the screw and the bearing as Figure (6-2) shows.

X-axis

Figure 6-2 Axis of motion

Y-axis

6.3 Motor support

Three steps are followed to build motor support. Cutting the square steel tubes with the scale dimensions, drilling and welding the cut pieces inside frame as Figure (6-3) shows.

Figure 6-3 Motor support

6.4 The arm

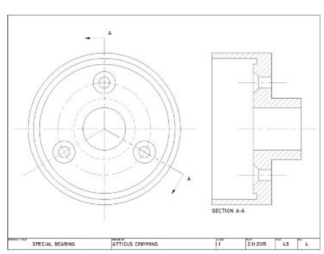
Three steps are followed to build the arm. Cutting the pipe with the scale dimensions, bending the pipe in the needed shape, and welding the arm with motor shaft as Figure (6-4) shows.

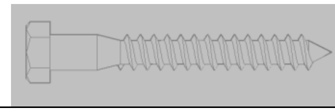
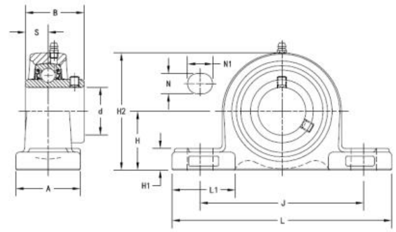
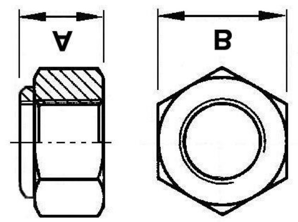
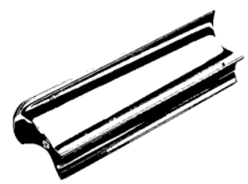
Figure 6-4 Arm

6.5 Assembly

After producing the car washing machine components, the following components are needed for assembly as Table (6-1) shows.

Table 6-1 Connecter parts of machine

Item number	Part name	Figure shape	Number of parts
1	Bearing		4

2	Screw Shaft		2
3	Bearing house		4
4	Nut of screw		4
5	Sliders		4

Four steps are needed to assemble the machine:

1- Start with pushing the screw in bearing house as Figure (6-5) shows. Press slightly to push the ball bearing house; the ball bearing should slide easily in place without using a hummer or any other metal object to push the ball bearing in the bearing house.

Figure 6-5 Bearing house and screw in x-axis

2- Repeat this process one more time to put the screw in bearing house as Figure (6-6) shows.

Figure 6-6 Bearing house and screw in y-axis

3- Take one coupling in the screw shaft, and another in the motor as Figure (6-7) shows, and repeat this process for another motor and the shaft of stand that holds the motor.

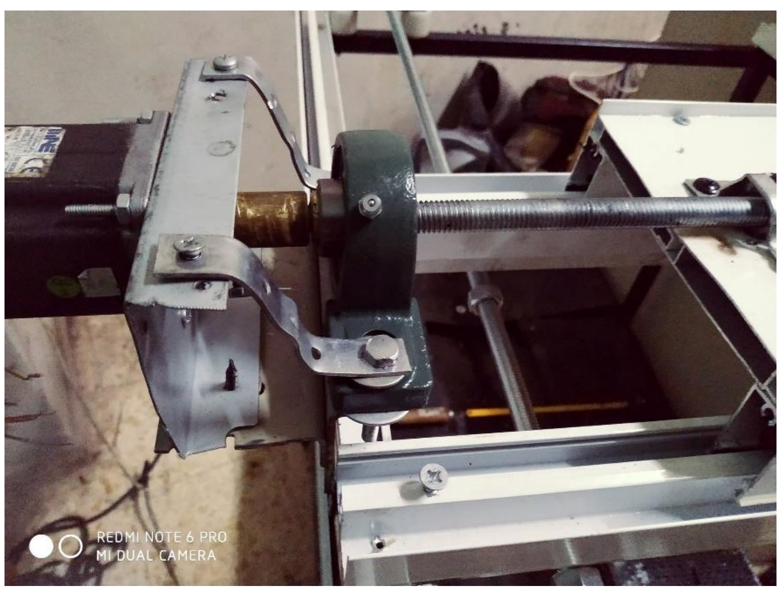


Figure 6-7 Coupling in screw shaft

4- Connect the arm with the shaft of motor as Figure (6-8) shows.

Figure 6-8 Arm

7.Conclusion and Recommendations

7.1 Conclusion

The project is a mechanical device setup that is used to wash the car collectively, when placing a car to be washed, a sensor transmits the signal to Arduino controller which transmits a signal to the motor to operate so the washing process begins.

The project is selected to achieve many benefits. Among them, washing cars without the touching which protect the car body from scratches, good cleaning by using chemical materials that remove all dirt from the car body, the whole process is done in short time and low electrical and water consumption, and the construction of this project is easy to use and accessible to everyone, safe to operate and easy to maintain.

7.2 Recommendations

We recommend taking these points into consideration before implementing the full-scale project.

The prototype was built with a scale of (1:7.5), so some dimension adjustments were made to fit the model. Stepper motors are used in the prototype because it's low cost, easy to find, and easy to use, instead of three phase motors which must be used in the full-scale project. Moreover, the applied load in the prototype is very low compared to the real load in the full-scale project, so it's not necessary to use three phase motor, stepper motors are sufficient to operate.

The main problem we faced throw implementing the project was financial problem, and obtaining some of the parts of the projects, so we recommend that the projects funds should be provided at the beginning of the project.

7.3 Future work

The following tasks are suggested as future work:

1- Increasing the safety in the machine by building a system that can determines if the window of the car is open or not and stop the machine if the window is open or somebody is out of the car or near it.
2- Reduce consumption by building water filtration system to recycle used water to clean cars, and modify the code to move the machine depending on the dimensions of car.
3- Increasing the machine space to be able to wash vans and trucks.
4- Developing the machine to be able to wash inside of cars.

8.Time and Cost Managements

8.1 Estimated project Cost.

In this section, we will explain the approximate cost needed to build the Automatic car washing machine system. Table (6-1) shows the parts and equipment needed to build the machine and their estimated costs.

Table 6-1 Cost table

Elements	**Number of elements**	**Cost**
Induction motor (3ph) with-(5hp)	2	900 Nis
Servo motor - (1hp) and servo driver	1	1500 Nis
Motor pump with 5hp	1	1800 Nis
Air fan motor 2.6kw	3	1000 Nis
Variable speed driver	1	700 Nis
Contactor	3	400 Nis
Thermal relay (overload)	1	130 Nis
Phase sequence protection relay	1	200 Nis
Ultrasonic sensor	3	300 Nis
Arduino	1	250 Nis
Power supply	1	500 Nis
Steel	-	3000 Nis
Nozzle	22	400 Nis
Other Parts	-	3000 Nis
Total	-	14110 Nis

8.2 Feasibility study

This table (6-2) shows the capital recovery period of the project.

Table 6-2 Feasibility study

	Quantity	Nis
Number of cars washed daily	30	-
The cost of washing one car	-	20
Water consumption of one car	120 L	1.44
Total power consumption of one car	9 kw/h	5.22
Other consumption	-	5

Total revenue per day	600 Nis
Water consumption per day	120*0.1*30 = 36 Nis
Total power consumption per day	9*0.58*30 = 156.6 Nis
Other consumption per day	150 Nis
Daily Place cost	53.7 Nis
Total consumption	396.3 Nis
Net profit	204 Nis

The time that needed to back the total cost = Total cost/net profit

$$t = \frac{14110}{204}$$

$$t = 66.69\ day$$

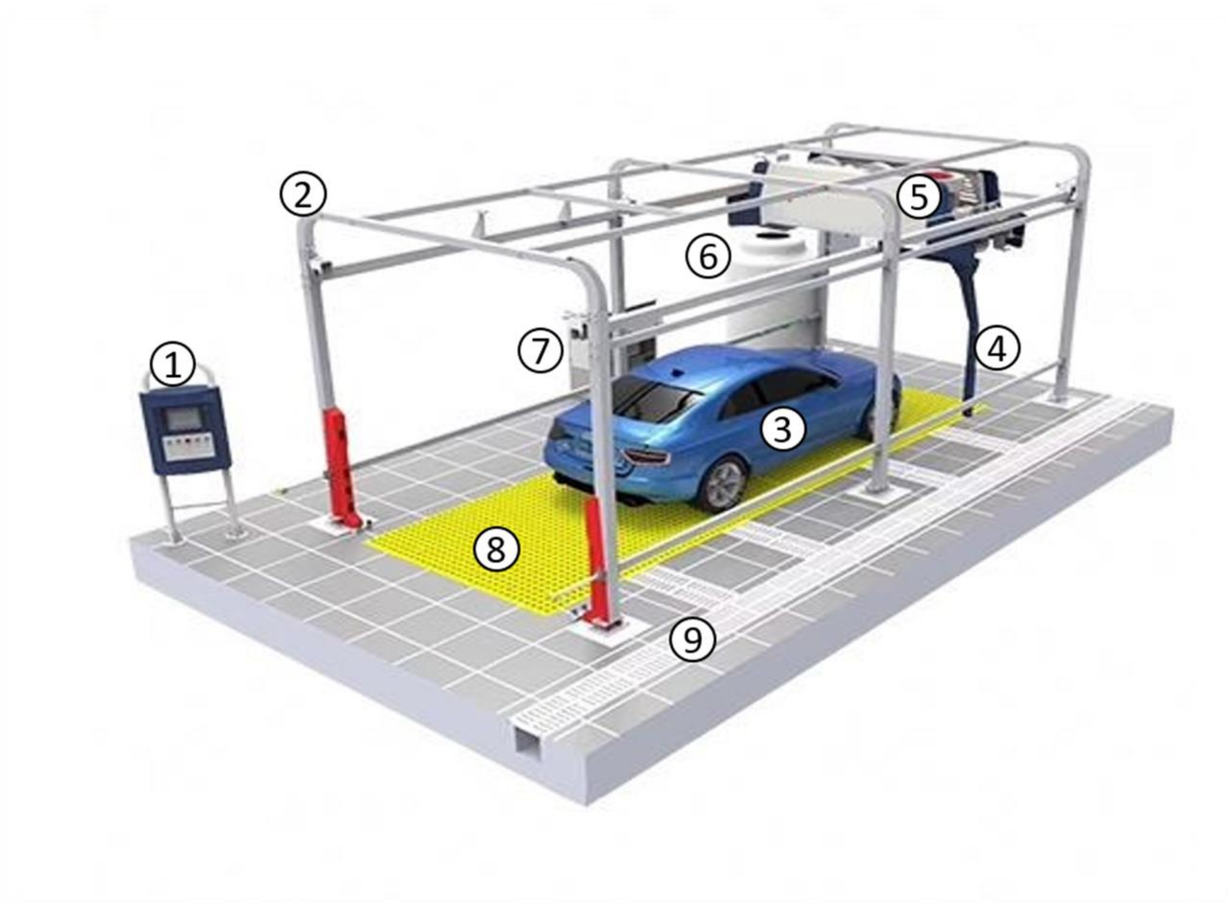
8.3 The project time schedule

In this section we will shows time plan of the introduction of project during the first semester (twenty-two weeks) as shown Table (6-3). Some tasks are done in parallel and some are done respectively.

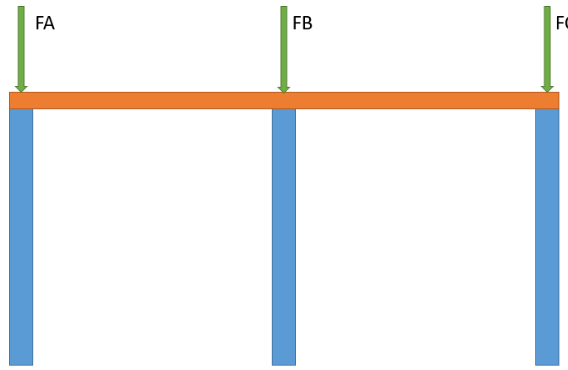
Table 6-3 Time table

Number Of Week / **Tasks**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
Identification of Project Ide																						
Writing Project Proposal																						
Introduction Chapter 1																						
Work principle of car washing machine																						
Mechanical Design Chapter 4																						
Electrical Design Chapter 5																						
Control Design Chapter 6																						
prototype																						

Appendix A



1	2	3	4	5	6	7	8	9
push button(Start)	Fram	The car	Arm	Body of machine	Tank of water	Box of wax	Car position	Sewage drainage



A1 Forces in each column of farm (2).

This machine is based on six columns, each column supports the machine, so that each column has a specific force to withstand, and this force should be evenly distributed over the columns, so we start by calculating these forces in the columns.

M= 500Kg

$$W = M * g \tag{3.1}$$

W: the machine weight.

M: the machine mass.

$W = 500 * 10 = 5000N = 5KN.$

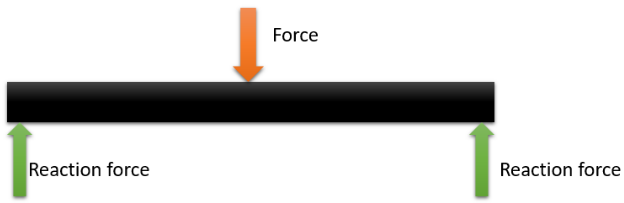


Figure 3-10 reaction force

The weight of the machine is dividing equally on the two sections of the frame.

$$F_A = F_B = \frac{W}{6} \tag{3.2}$$

$F_A = F_B = 833.3N$

Then;

$F_A = F_B = F_C = F_D = F_E = F_F = 833.3\ N.$

$F_A, F_B, F_C, F_D, F_E, F_F$: The forces acting vertically to the supporting frame Columns.

A2 Dimension of the beam

As previously indicated, we have seen that this machine contains six columns, and the total force has been calculated on these columns, through these forces and by reference to the metal material data tables we can find the dimensions of the columns of the structure that support the machine.

Step 1: calculate the reaction force from the equation (3.3).

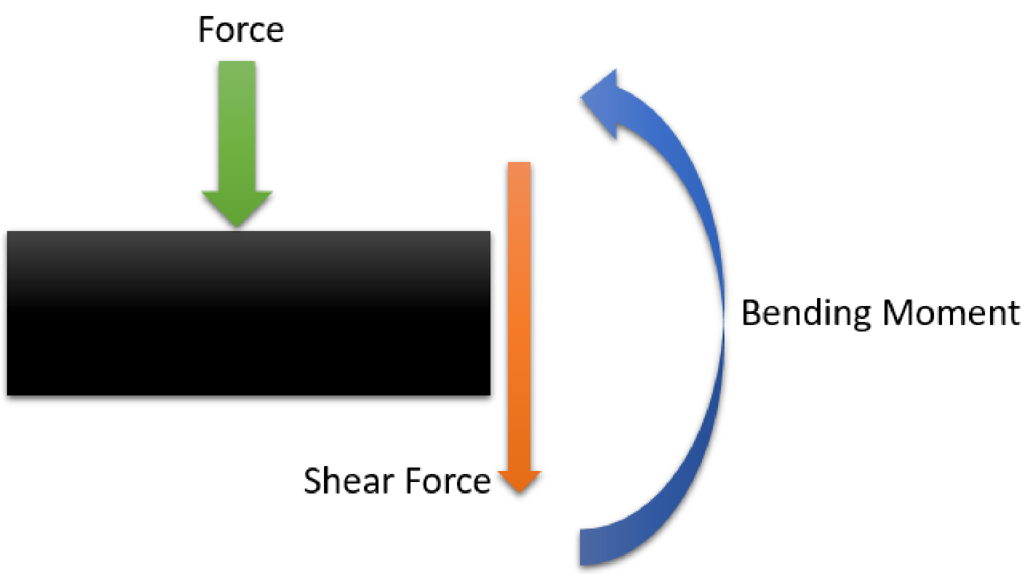


Figure 3-11 shear force and bending moment

$$\sum F_y = 0 \tag{3.3}$$

$R_1 + R_2$= W

Where, (R_1, R_2):The reaction force in the two sides of shaft.

$$R_1 = R_2 = \frac{W}{6} = \frac{5000}{6} = 833.3N$$

$$R_1 = R_2 = F_A = F_B$$

Step 2: Find the moment in the beam from equation (3.4).

$$M = F * R = F * L/2 \tag{3.4}$$

L: Length of the beam = 3750(mm) = 3.75(m)

$M = 833.3 * 3.75 = 3124.8(N.M) = 3.1248(KN.M)$

Step 3: Now using equation (3.5) to find the deflection of the beam.

$$y_{max} = \frac{F * l^3}{48 * E * I} \tag{3.5}$$

Where;

y_{max}: The maximum allowed deflection of the beam, and we calculate it by the following equation: $y_{max} = \frac{y_{all}}{n}$ where:

y_{all}: The allowable deflection for the beam.

n: the factor of safety=2.5

$l = 0.5L$

E: the modulus of elasticity.

E= 200 GPA

Step 4: compute the moment of inertia by equation (3.6).

I: The moment of inertia about the natural axis of the beam.

$$I = \frac{1}{12}bh^3 - \frac{1}{12}b_1h_1^3 \tag{3.6}$$

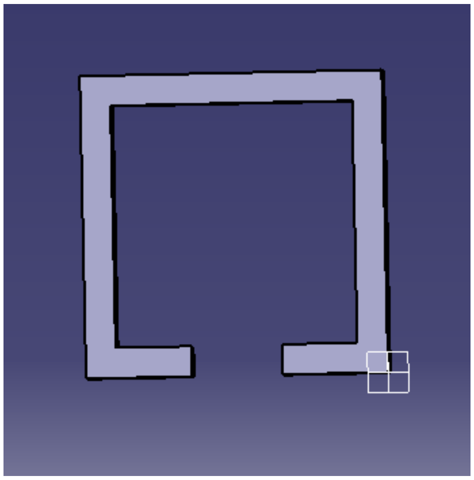


Figure 3-12 front view of beam

Where:

b: The Width of the beam.

h: The Height of the beam.

b_1: The width – thickness.

h_1: The Height – thickness.

Step 5: applying the equation (3.7):

$$\sigma_b = \frac{M\ C}{I} \qquad (3.7)$$

Where:

σ_b: the bending stress on the longitudinal beam, and we calculate it by the following equation $\sigma_b = \frac{S_y}{n}$, were:

S_y:the yield strength, and from Table A-20:

S_y for steel (1095) equal 460 Mpa.

n: the factor of safety equal 2.5

Now starting with equation (3.5):

$$y_{max} = \frac{F * l^3}{48 * E * I}$$

$$y_{max} = \frac{y_{all}}{n}$$

$$y_{max} = -2 \times 10^{-2}/2.5 \ \ = -8*10^{-4}m$$

Calculating I:

$$I = \frac{1}{12}bh^3 - \frac{1}{12}b_1h_1^3$$

$$I = \left[\frac{1}{12} \times 0.25(0.25)^3\right] - \left[\frac{1}{12} \times 0.234(0.234)^3\right] = 3.255 \times 10^{-4}$$

Then,

$$\sigma_b = \left[\frac{56.25 \times 0.125}{3.255 \times 10^{-4}}\right] = 21.6014ksi$$

From tables the [σ_{all}] of steel equal to 24 ksi, so [$\sigma_b < \sigma_{all}$], we conclude from this value that the material is in the safe mode with these dimensions.

A3 The bearing affection

It is certain that this machine will run on wheels, and these wheels need bearing, so it is necessary to know the dimensions available for the wheels to can carry the machine, see (figure (3.3.3.1): the free body diagram of one bearing.

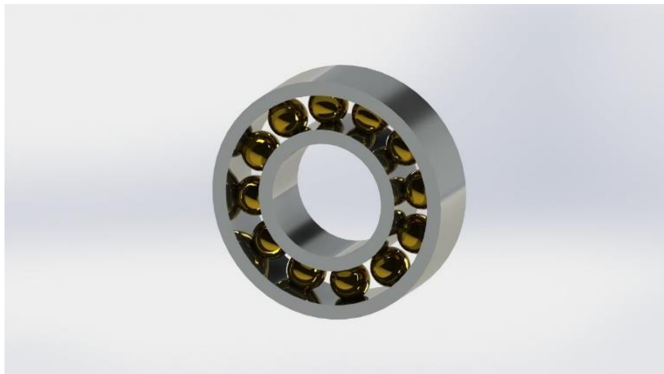


Figure 3-13 the bearing

Step 1: using equations (3.8), (3.9), (3.10) and (3.11) to compute the resultant force in the bearing.

$$F_x = \mu * N + m * a \tag{3.8}$$

$$N = \rho_w * \vartheta_t * g \tag{3.9}$$

μ:The coefficent of friction between the belt and the roller, and equals 0.05.

N:The normal Force affected on wheel.

ρ_w: The maximum density of the handing body.

ϑ_t:The maximum volume of the trunk.

a: acceleration of the belt, equals 0.

$$\rho_w = \frac{M}{\vartheta_t} \tag{3.10}$$

$$\rho_w = \frac{500}{11000} = \frac{0.4545g}{cm3}$$

$$N = 0.4545 * 11 * 9.8 = 49N$$

$$F_x = 0.05 * 29429.4 = 2.45N$$

$$F_y = \frac{833.3}{2} = 416.65\text{N}$$

$$F_r = \sqrt{(F_x{}^2) + (F_y{}^2)} \tag{3.11}$$

$F_r = \sqrt{(1.47145^2) + (0.41665^2)} = 1.528\text{KN}$

Now, calculation the design radial load from (3.12):

$$F_D = a_f * V * F_r \tag{3.12}$$

F_D:Design Radial load.

V: Rotation factor, and equal 1.2 (rotating outer ring).

F_r: Radial load on te bearing.

a_f: Application factor used because loads are often variable (non-steady) and may increase during operation, and equals 1.2 (machinery with no impact).

$F_D = 1.2 * 1 * 1528 = 1.8336$ KN.

Then now the find the X_D, and using equation (3.13):

$$X_D = \frac{L_D}{L_{10}} \tag{3.13}$$

$$X_D = \frac{L_D}{1 * 10^6}$$

X_D:Life ratio.

L_D:Designe life, and equals 30000(generaly industrial machinery).

L_{10}:Number of revolutions, and equals $1 * 10^6$(based on 90% reliability).

$$X_D = \frac{30000 * 14 * 60}{1 * 10^6} = 25.2$$

Now, calculate the required catalog rating (C_{10}) and using equation (3.14).

$$C_{10} = X_D^{1/a} * F_D \tag{3.13}$$

a: 3 (ball bearing).

$C_{10} = 25.2^{1/3} * 4503.6 = 13203.63N = 13.203KN.$

Now, check the catalog and select a suitable bearing.

From table 11-2.

$C_{10} = 7.02$, Bore=12mm, OD=32mm, $C_0 = 3.1$,E2.6201-27.

Here we find the diameter the bearing bore, using the low of factor of safety [equation (3.15)] and shear stress [equation (3.16)].

$$n = \frac{S_y}{\tau} \tag{3.15}$$

τ: shear stress.

S_y:The yield strength and from Table A-30: S_y For high carbon steel is 220Mpa .

n: Factor of safety and we have chosen it to be 4.

$$\tau = \frac{220 * 10^6}{4} = 55 * 10^6 Mpa$$

$$\tau = \frac{F_r}{A} \tag{3.16}$$

A: Area of bearing bore.

$$\tau = \frac{1528}{\frac{\pi}{4} d^2}$$

$$d^2 = \frac{4 * F_r}{\pi * \tau} \rightarrow d = \sqrt{\frac{4 * 3753}{\pi * 55 * 10^6}} = 9.3 * 10^{-3} m$$

$$d = 4.66mm.$$

These table show us the available dimensions for the bearing which is used in this machine. Dimensions

*Table 3-**Error! No text of specified style in document.**-1 dimensions* [33]*s*

D		9	Mm
D		30	Mm
B		10	Mm
d_2	≈	15.3	Mm

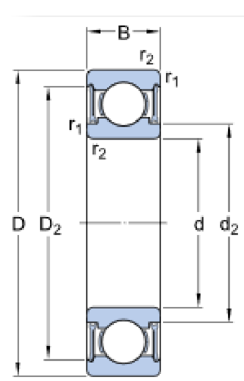


*Figure 3 -**Error! No text of specified style in document.**-1 dimensions of bearing*

D_2	≈	25.28	Mm
$r_{1,2}$	min.	0.6	Mm

Calculation data

*Table 3-**Error! No text of specified style in document.**-2 calculation data*

Basic dynamic load rating	C		1.528 kN
Basic static load rating	C_0		0.764 kN
Fatigue load limit	P_u		0.1 kN
Reference speed			500 r/min
Limiting speed			1000 r/min
Calculation factor	k_r		0.035
Calculation factor	f_0		12.9

Mass

*Table 3-**Error! No text of specified style in document.**-3 mass of bearing*

Mass bearing	0.35	kg

Bolt design

Load factor [n]:

The weight of the machine = 30000N=30KN

The number of plots is 48, The Force (P) calculated by using the equation (3.17):

$$P = \frac{F}{N} \quad (3.16)$$

$P = \frac{30}{24} = 0.0333KN = 333N$, for each bolt.

The up plate was fixed on the wall and the down plate was fixed with up plate by bolts.

$D = 20mm$
$E = 25mm$

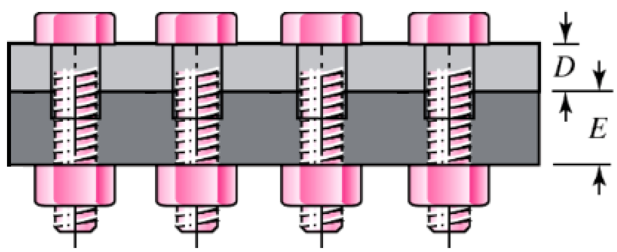


*Figure 3-**Error! No text of specified style in document.**-2 fixed plate by bolts*

The length and the threaded length of the bolt can be calculated from equation (3.17) and (3.18):

$$l = l_d + l_t \quad (3.17)$$

$l = 20 + 25 = 45mm$

From table A-31 at d=12mm → H=10.8mm.

Standard threaded length.

$$L_t = 2d + 6 \quad (3.18)$$

$L_t = 2(12) + 6 = 30mm$

The total length must be $L > l + H \rightarrow L > (45 + 10.8) \rightarrow L > 55.8mm$

Standard size from (Table A-17):

$L = 60mm$

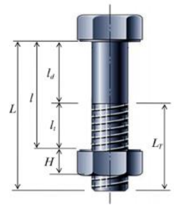


*Figure 3-**Error! No text of specified style in document.**-3 dimension of bolt*

Now, with reference to the figure shown:

$ld = 60 + 30 = 30mm$

Threaded length in the clamped zone:

$l_t = 45 - l_d = 45 - 30 = 15mm$

Cross sectional areas:

$$A_d = \frac{\pi(12)^2}{4} = 113mm^2 \qquad (3.17)$$

Table 8-1: $A_t = 84.3mm^2$

Bolt stiffness:

$$k_b = \frac{113(84.3)207}{113(15) + 84.3(30)} = 466.8MN/n$$

Calculating member stiffness: 72

There are three frusta as shown in the figure, where

$d_w = 1.5(12) = 18mm$

$D_1 = 2(20tan30°) + 18 = 41.09mm$

Upper Frustum:

$$\left.\begin{aligned} t &= 20mm \\ D &= 18mm \\ d &= 12mm \\ E &= 207GPa \end{aligned}\right\} \rightarrow k_1 = 4470MN/m$$

Central Frustum:

$$\left.\begin{aligned} t &= 2.5mm \\ D &= 41.09mm \\ d &= 12mm \\ E &= 100GPa \end{aligned}\right\} \rightarrow k_2 = 52230MN/m$$

Lower Frustum:

$$\left.\begin{aligned} t &= 22.5mm \\ D &= 18mm \\ d &= 12mm \\ E &= 100GPa \end{aligned}\right\} \rightarrow k_3 = 2074MN/m$$

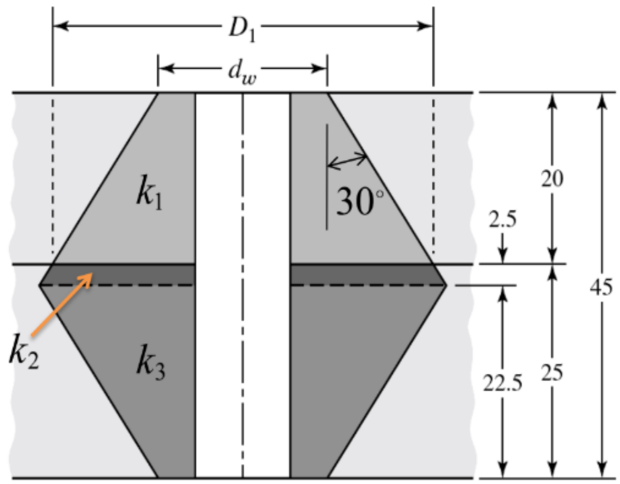


*Figure 3-**Error! No text of specified style in document.**-4 member stiffness*

Total member stiffness:

$$\frac{1}{k_m} = \frac{1}{k_1} + \frac{1}{k_2} + \frac{1}{k_3} \rightarrow k_m = \left(\frac{1}{k_1} + \frac{1}{k_2} + \frac{1}{k_3}\right)^{-1} \tag{3.19}$$

$$k_m = \left(\frac{1}{4470} + \frac{1}{52230} + \frac{1}{2074}\right)^{-1} = 1379MN/m$$

Stiffness constant of the joint:

$$C = \frac{k_b}{k_b + k_m} \tag{3.20}$$

$$C = \frac{466.8}{466.8 + 1379} = 0.253$$

Table 8-11: for ISO class 8.8 we have:

$$S_p = 600MPa$$

Assuming reused connection:

$$F_i = 0.75F_p = 0.75S_pA_t = 0.75(600)(84.3) = 37935N = 37.9KN$$

Factor of safety guarding against bolt yielding:

$$n_y = \frac{S_p A_t - F_i}{CP} \quad (3.21)$$

$$n_y = \frac{600(84.3) - (37.9 \times 10^3)}{0.253(10.6 \times 10^3)} = 4.73$$

Factor of safety guarding against joint separation:

$$n_0 = \frac{F_i}{P(1 - C)} \quad (3.21)$$

$$n_0 = \frac{37.9 \times 10^3}{10.6 \times 10^3 (1 - 0.253)} = 4.79$$

Overall factor of safety of the connection:

$n =$ Min (n_y, n_0) = 4.73

A4 Bearing in bolts loaded:

We calculate them for bolts that tie between the upper structure and columns using equation (3.22).

$$\sigma_b = \frac{F}{2td} = \frac{S_p}{n_d} \quad (3.22)$$

$\frac{F}{2}$: *is transmitted by each of the splice plates, but since the areas of the splicr plates are half of the center bars , the stresses associated with the plates are the of center plates.*

t: *Thickness of the member and is* $1.6(cm) = 0.6272(in)$..

$1(in) = 2.45(cm)$

d: *diameter of the bolt and is* $2.4(cm) = 0.936(in)$

S_p: *From Table* $8 - 9$ *is* $85ksi$.

From equations (3.21) and (3.22) :

$$F = \frac{2tdS_p}{n_d}$$

$$F = \frac{2 * 0.6272 * 0.936 * 85}{1.5} = 66.533kpsi = 296KN$$

A5 Bearing in member, all bolts active.

Now, using equations (3.21) and (3.22) but use [S_y] instead of [S_p] as following:

$$\sigma = \frac{F}{2td} = \frac{S_y}{n_d} \tag{3.23}$$

S_y: The yield strength for steel, and from Table A-20, it is 54 kpsi.

By applying the equation in (3.23):

$$F = \frac{2tdS_y}{n_d} = \frac{2 * 62.72 * 0.936 * 54}{1.5} = 42.27kip = 188.01KN$$

A6 Shear in Bolts, all bolts active

$$\tau = \frac{F}{4 \times A_r} = 0.577\frac{S_p}{n_d} \tag{3.24}$$

The force doesn't affect on the toothed part of the bolt because it is the weakest part of plot, but on the other part.

A_r: Area of the cross section of the bolt.

$$F = 0.577\pi d^2\ \frac{S_p}{n_d} = 0.577 * \pi * 0.936^2 * \frac{85}{1.5} = 70kpsi = 400KN$$

A7 Edge shearing of member, at low margin bolts.

The force doesn't affect on the toothed part of the bolt because it is the weakest part of bolt, but on the other part, the shear from equation (3.25) equal:

$$\tau = \frac{F}{4 \times a \times t} \tag{3.25}$$

τ: Shear.

a: the dimension shown.

$$a = \frac{W}{2} = \frac{D}{2} = \frac{2}{2} = 1cm = 0.3936(in).$$

W: Width of the member shown.

But the force can be calculated from (3.26):

$$F = \frac{4 * \mathrm{a} * \mathrm{t} * 0.577 * \mathrm{S_y}}{\mathrm{n_d}} \quad (3.26)$$

$$F = \frac{4 * 0.3936 * 0.6272 * 0.577 * 54}{1.5}$$

$$F = 20.51 = 91.256kN$$

Figure (…) demonstrates the edge shearing of member.

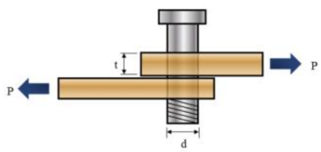


*Figure 3-**Error! No text of specified style in document.**-5 the edge shearing of member* [34]

A8 Tensile yielding of member across bolt holes

Start of calculating the area of the member from equation (3.27):

$$A_{member} = w * t \quad (3.27)$$

$$A_{member} = 2.3in^2.$$

A_{member}: Area of the member.

w: width of the member and equal 3 (cm)= 1.2(in)

$$\sigma = \frac{S_y}{n_d} = \frac{F}{A} \rightarrow F = \frac{S_y * A}{n_d} = 107.25kpsi = 472kN.$$

3.3.4.6 Member yield

$$F = \frac{w * t * S_y}{n_d} = \frac{1.18 * 1.96 * 54}{1.5} = 124.89kpsi = 370.34kN$$

$$F = \begin{cases} 296(kN)\ based\ on\ bearing\ in\ bolts. \\ 188.01\ (kN)\ based\ on\ bearing\ in\ member \\ 400\ (kN)\ based\ on\ shear\ in\ bolts\ shear\ in\ shank \\ 91.256\ (kN)\ based\ om\ edge\ (shearing\ of\ member) \\ 472\ (kN)\ based\ n\ tensile\ yielding\ of\ member\ across\ the\ bolts \\ 370.34\ (kN) based\ on\ tensile\ yielding\ of\ members\ away\ from\ the\ bolts \end{cases}$$

Limiting value of force is 91.256 KN

$91.256\ kN\ > 30\ kN$

We chose the smallest force, so that the press force is not above it;

In addition, the press force is much smaller than the bolt force.

A9 Buckling on the column

Now we will find the buckling force that the column of the frame that carry the machine from equation (3.28):

$$F = \frac{\pi^2 * E * I}{I_k^2 * V} \tag{3.28}$$

E: Elasticity Module=2.1*10^5 (N/mm^2) (steel).

V: Factor of safety=3.5.

$I_K = 1$: Free Buckling Length (mm).

I: Area moment of inertia (mm^4).

Calculating the area moment of inertia:

$A_1 = 20(1.6) = 32\ \text{mm}^2$

$y_1 = 0.8\ mm$

$I_1 = \frac{1}{12} \times 12 \times 1.6^3 = 4.1 mm^4$

$A_2 = (0.8)16.8 = 26.88 mm^2$

$I_2 = \frac{1}{12} \times 1.6 \times 16.8^2 = 632.2 mm^4$

$y_2 = 10\ mm$

$A_3 = A_1 = 32\ \text{mm}^2$

$I_3 = \frac{1}{12} \times 12 \times 1.6^3 = 4.1 mm^4$

$y_3 = 19.2 mm$

$$I = I_1 + I_2 + I_3 \qquad (3.29)$$

$$I = 640.4\ mm^4$$

Now, Finding the Buckling Force:

$$F = \frac{\pi^2 * 2.1 * 10^5 * 640.4}{1^2 * 3.5} = 3.788kN$$

$$f = \frac{F}{x^{\cdot}}$$

f: the critical force without occurring buckling.

$x^{\cdot}$: the load factor and it's equals 20.62.

$$f = \frac{13400}{20.62} = 0.00151N$$

Buckling analysis as shown as in figure ():

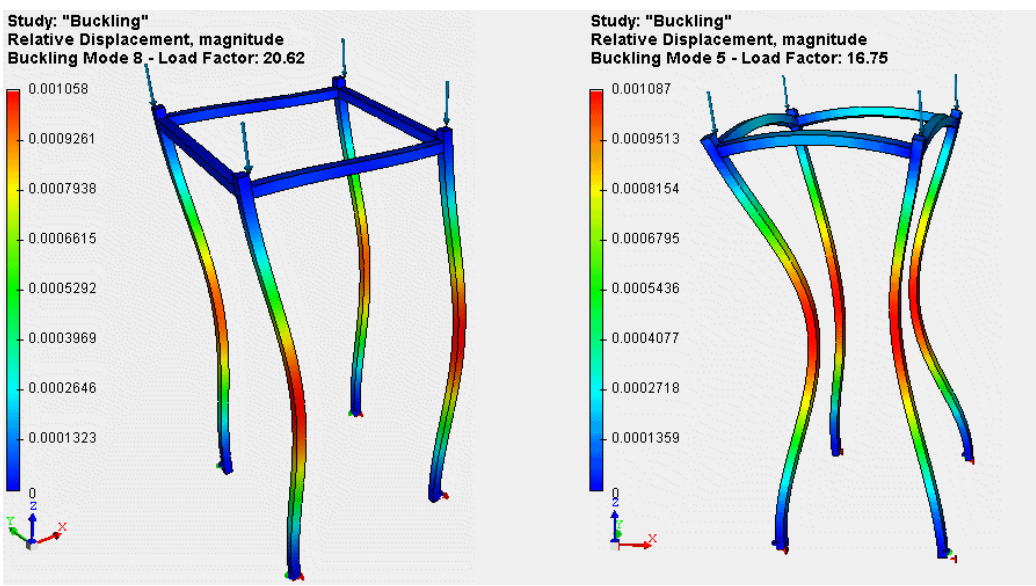


*Figure 3-**Error! No text of specified style in document.**-6 Buckling analysis* [35]

The rod can withstand the Buckling force, because its less than the pull force. Depicted in Figure (3.3.5.1) The four Buckling cases.

A10 Angular velocity.

we want the machine to move from the start to the end of car in 7 second, the time is important for calculate the angular velocity of the motor which is move the machine using the equation (3.30):

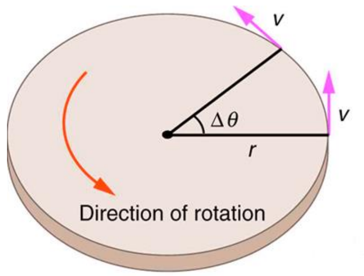


*Figure 3-**Error! No text of specified style in document.**-7 angular velocity and direction of rotation* [36]

$$S_f = S_i + V_i t + {}^1\!/_2\, at^2 \qquad (3.30)$$

S_f: the distance from the middle to the end of frame.

S_i: the initial distance, and equal (zero).

V_i:Initial velocity of the belt.

a: acceleration of the belt.

$3.5 = {}^1\!/_2\, a(3.5)^2$

$a = 0.571428 \text{m}/s^2$

$a = \ddot{\theta}$

$\ddot{\theta}$: angular acceleration of the gear.

r: radius of the gear.

$$\ddot{\theta} = \frac{a}{r} \qquad (3.31)$$

$$\ddot{\theta} = \frac{0.571428}{0.25} = 2.285$$

$1\, rev \rightarrow 2\pi d$

$? \rightarrow 2$

$$??rev = \frac{1 \times 2}{2\pi(0.25)} = 1.27\, rev/meter.$$

$$1.27\frac{rev}{meter}*\frac{1meter}{7\ second}*\frac{60sec}{1min}=10.919rpm\approx 11rpm$$

The specified motor is shown in fig (3.3.6.1).

To have a minimum speed of 11 rpm the motor must be with a speed of 1200 rpm and there will not use gears, but will use pulleys but equal to gear box with ratio of 1:100.

A11 The motors torque

The free body diagram of the conveyor pulley is depicted in figure (3.3.7.1), then to calculate the motors torque in this machine, we should use these equations [(3.32), (3.33), (3.34), (3.35) and (3.36)] as following:

$$\sum M = J\ddot{\theta} \qquad (3.32)$$

$$T = J\ddot{\theta} + (\mu * N + m * a)r \qquad (3.33)$$

$$m = 3000kg$$

$$N = 29429.4N = 29.4294KN \approx 30KN$$

$$\mu * N = 0.05 * 29429.4 = 1471.47N$$

$$m_{pulley} = \rho * v \qquad (3.34)$$

$$A = \pi(d_{out} - d_{in})^2 \qquad (3.35)$$

$$A = \pi(0.5 - 0.3)^2 = 0.04m^2$$

$$V = A * L$$

$$V = 0.5 * 0.02 = 8 \times 10^{-4}m^3$$

$$m_{pulley} = 7850 * 8 \times 10^{-4} = 6.28kg$$

$$J = \frac{1}{2}m_{pulley}R^2 \qquad (3.36)$$

$$J = \frac{1}{2}(6.28)(0.5)^2 = 0.785kg.m^2$$

m_{pulley}: the mass of the pulley.

m: the maximum total mass of two pulleys.

ρ: Density of high carbon steel and equals 7850kg/m^3

V: volume of the pulley.

d_{out}: the outer diameter of the pulley.

d_{in}: the inner diameter of the pulley.

$\therefore T = \left((0.785 * 0.1436) + (1471.47 + 3000 * 0.0357) * 0.5\right)$

$T = 78.94 N.M$

P = 3.987kW

Torque of shaft servo motor: -

$Tl = Tw * \frac{G}{\eta} \, N.m$

TL: Motor Shaft Conversion Load Torque [N·m]

TW: Load Torque[N·m]

Gear (Deceleration) Ratio G = Z1/Z2

Z1: Number of Gear Teeth on Motor Side

Z2: Number of Gear Teeth on Load Side

η: Gear Transmission Efficiency

TL=2.3 N.m

Power of motor = 0.723 kW

A12 Nozzle

Nozzles are frequently used to control the rate of flow, speed, direction, mass, shape, and/or the pressure of the stream that emerges from them.

Figure 3-4 Spray nozzle [13]

The nozzle used in this device is of the type of "Flat High Pressure Even Sprayer".

Selection of the Nozzle

Provides high and uniform impact capabilities. Even spray pattern eliminates the need to overlap patterns from adjacent nozzles.

Spray Angle - 5o to 65o.

Velocity of the flowing liquid through the nozzle can be calculated with the help of the equation of continuity.

Equation of continuity (3.37):

$$a_1 v_1 = a_2 v_2 \quad (3.37)$$

Where: -

a_1, a_2 : are area of cross-section of the nozzle inlet and outlet resp.

v_1, v_2 : are velocity of the fluid or liquid flowing in and out through the nozzle.

Formula that can be used in this device for various calculations of the numerical parameters.

The flow rate of the fluid can be calculated with the help of the following formula as in these equation (3.38):

$$Q = P * n / \Delta P \quad (3.38)$$

Where the various parameters are:

Q : Fluid flow rate in m3/s.

P : Power of the pump in watt.

n : Efficiency of the pump.

ΔP : Change in pressure in Pa.

The change in pressure for the nozzle inlet and outlet can be calculated with help of the Bernoulli's equation, which can be given as in following equation (3.39):

$$\Delta P = ((v_2)^2 - (v_1)^2)/2 + \Delta Z * g + \Delta Pstatic / d \quad (3.39)$$

ΔP : Change in pressure in Pa

v_1, v_2 : Velocity of inlet & outlet fluid in m/s.

ΔZ : Change in height in m.

g : Acceleration due to gravity m/s2.

d : Density of the fluid in kg/m3.

$\Delta Pstati$: Change in pressure at static condition in Pa.

Specifications for the nozzle:

Velocity of the fluid through the outlet:

r_1 = 20mm	r_2 = 5mm
a_1 = 3.14*20*20	a_2 = 3.14*5*5
= 1256 mm2	= 78.5 mm2
v_1 = 5 m/s (for the inlet)	v_2 = (a1*v1) /a2 = 80m/s

Change in pressure for inlet and outlet:

ΔZ= 1m (considering height of 1m).

$\Delta Pstatic$ = 0 (at static condition pressure diff. is 0).

ΔP= (6400-25)/2 +1*10 + 0

= 3197.5 Pa

Flow rate of the fluid:

Efficiency n, = 60%   Power of the pump for one nozzle = 1361.93

For (11) nozzles = 11*1361.93= 5 HP

Appendix B

A.1 Dimensions of Bearing

TABLE 11-2

Dimensions and Load Ratings for Single-Row 02-Series Deep-Groove and Angular-Contact Ball Bearings

Bore, mm	OD, mm	Width, mm	Fillet Radius, mm	Shoulder Diameter, mm d_S	d_H	Load Ratings, kN Deep Groove C_{10}	C_0	Angular Contact C_{10}	C_0
10	30	9	0.6	12.5	27	5.07	2.24	4.94	2.12
12	32	10	0.6	14.5	28	6.89	3.10	7.02	3.05
15	35	11	0.6	17.5	31	7.80	3.55	8.06	3.65
17	40	12	0.6	19.5	34	9.56	4.50	9.95	4.75
20	47	14	1.0	25	41	12.7	6.20	13.3	6.55
25	52	15	1.0	30	47	14.0	6.95	14.8	7.65
30	62	16	1.0	35	55	19.5	10.0	20.3	11.0
35	72	17	1.0	41	65	25.5	13.7	27.0	15.0
40	80	18	1.0	46	72	30.7	16.6	31.9	18.6
45	85	19	1.0	52	77	33.2	18.6	35.8	21.2
50	90	20	1.0	56	82	35.1	19.6	37.7	22.8
55	100	21	1.5	63	90	43.6	25.0	46.2	28.5
60	110	22	1.5	70	99	47.5	28.0	55.9	35.5
65	120	23	1.5	74	109	55.9	34.0	63.7	41.5
70	125	24	1.5	79	114	61.8	37.5	68.9	45.5
75	130	25	1.5	86	119	66.3	40.5	71.5	49.0
80	140	26	2.0	93	127	70.2	45.0	80.6	55.0
85	150	28	2.0	99	136	83.2	53.0	90.4	63.0
90	160	30	2.0	104	146	95.6	62.0	106	73.5
95	170	32	2.0	110	156	108	69.5	121	85.0

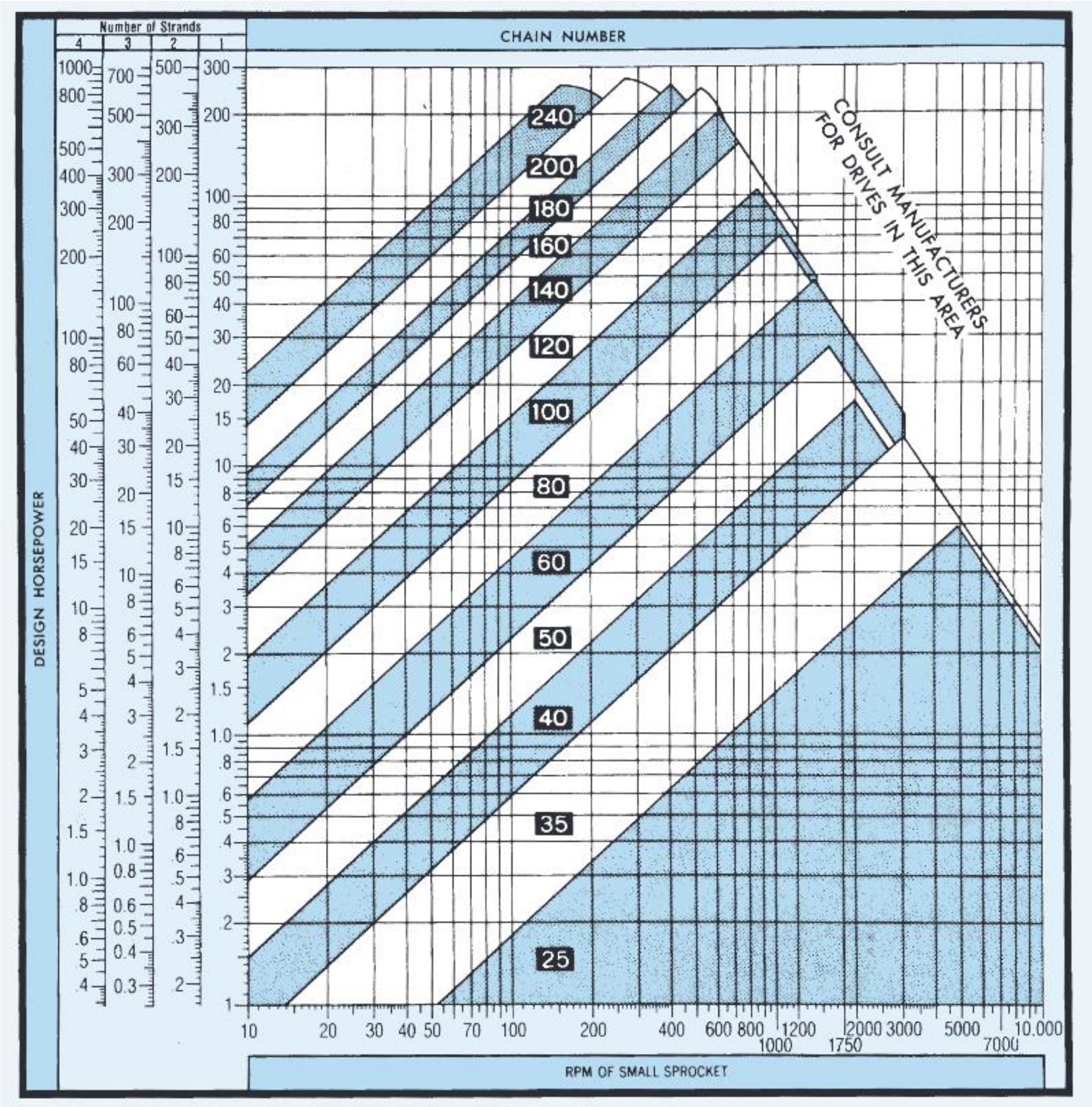
A.2 Mechanical Properties of steel 1080

Table A–20

Deterministic ASTM Minimum Tensile and Yield Strengths for Some Hot-Rolled (HR) and Cold-Drawn (CD) Steels [The strengths listed are estimated ASTM minimum values in the size range 18 to 32 mm ($\frac{3}{4}$ to $1\frac{1}{4}$ in). These strengths are suitable for use with the design factor defined in Sec. 1–10, provided the materials conform to ASTM A6 or A568 requirements or are required in the purchase specifications. Remember that a numbering system is not a specification.] *Source:* 1986 SAE Handbook, p. 2.15.

1 UNS No.	2 SAE and/or AISI No.	3 Processing	4 Tensile Strength, MPa (kpsi)	5 Yield Strength, MPa (kpsi)	6 Elongation in 2 in, %	7 Reduction in Area, %	8 Brinell Hardness
G10060	1006	HR	300 (43)	170 (24)	30	55	86
		CD	330 (48)	280 (41)	20	45	95
G10100	1010	HR	320 (47)	180 (26)	28	50	95
		CD	370 (53)	300 (44)	20	40	105
G10150	1015	HR	340 (50)	190 (27.5)	28	50	101
		CD	390 (56)	320 (47)	18	40	111
G10180	1018	HR	400 (58)	220 (32)	25	50	116
		CD	440 (64)	370 (54)	15	40	126
G10200	1020	HR	380 (55)	210 (30)	25	50	111
		CD	470 (68)	390 (57)	15	40	131
G10300	1030	HR	470 (68)	260 (37.5)	20	42	137
		CD	520 (76)	440 (64)	12	35	149
G10350	1035	HR	500 (72)	270 (39.5)	18	40	143
		CD	550 (80)	460 (67)	12	35	163
G10400	1040	HR	520 (76)	290 (42)	18	40	149
		CD	590 (85)	490 (71)	12	35	170
G10450	1045	HR	570 (82)	310 (45)	16	40	163
		CD	630 (91)	530 (77)	12	35	179
G10500	1050	HR	620 (90)	340 (49.5)	15	35	179
		CD	690 (100)	580 (84)	10	30	197
G10600	1060	HR	680 (98)	370 (54)	12	30	201
G10800	1080	HR	770 (112)	420 (61.5)	10	25	229
G10950	1095	HR	830 (120)	460 (66)	10	25	248

A.3 Figure (19-1): single-strand Roller Chain Selection Chart



A.5 Service Factors K_s

Table 17-6: V-belt service factors, K_s

Load Type	Driven machine type	Soft starts: AC motors: Normal torque[a]; DC motors: Shunt-wound; Engines: Multiple-cylinder			Heavy starts: AC motors: High torque[b]; DC motors: Series-wound, compound-wound; Engines: 4-cylinder or less		
		<6 h per day	6–15 h per day	>15 h per day	<6 h per day	6–15 h per day	>15 h per day
Smooth	Agitators, blowers, fans, centrifugal pumps, light conveyors	1.0	1.1	1.2	1.1	1.2	1.3
Light Shock	Generators, machine tools, mixers, gravel conveyors	1.1	1.2	1.3	1.2	1.3	1.4
Medium Shock	Bucket elevators, textile machines, hammer mills, heavy conveyors	1.2	1.3	1.4	1.4	1.5	1.6
High Shock	Crushers, ball mills, hoists, rubber extruders	1.3	1.4	1.5	1.5	1.6	1.8
Heavy Shock	Any machine that can choke	2.0	2.0	2.0	2.0	2.0	2.0

FOR SPEED - INCREASING DRIVES OF,

Speed ratio 1.00 to 1.24 : Multiply service factor by 1.00
Speed ratio 1.25 to 1.74 : Multiply service factor by 1.05
Speed ratio 1.75 to 2.49 : Multiply service factor by 1.11
Speed ratio 2.50 to 3.49 : Multiply service factor by 1.18
Speed ratio 3.50 & over : Multiply service factor by 1.25

A.6 Horsepower Rating of single Strand Roller Chains, No.40

Table 19-5(*c*): Horsepower ratings of single strand roller chain, No. 40

# of teeth in small sprocket	Revolutions Per Minute – Small Sprocket																								
	10	25	50	100	180	200	300	500	700	900	1000	1200	1400	1600	1800	2100	2500	3000	3500	4000	5000	6000	7000	8000	9000
11	0.06	0.14	0.27	0.52	0.91	1.00	1.48	2.42	3.34	4.25	4.70	5.60	6.49	5.57	4.66	3.70	2.85	2.17	1.72	1.41	1.01	0.77	0.61	0.50	
12	0.06	0.15	0.29	0.56	0.99	1.09	1.61	2.64	3.64	4.64	5.13	6.11	7.09	6.34	5.31	4.22	3.25	2.47	1.96	1.60	1.15	0.87	0.69	0.57	
13	0.07	0.16	0.31	0.61	1.07	1.19	1.75	2.86	3.95	5.02	5.56	6.62	7.68	7.15	5.99	4.76	3.66	2.79	2.21	1.81	1.29	0.98	0.78		
14	0.07	0.17	0.34	0.66	1.15	1.28	1.88	3.08	4.25	5.41	5.98	7.13	8.27	7.99	6.70	5.31	4.09	3.11	2.47	2.02	1.45	1.10	0.87		
15	0.08	0.19	0.36	0.70	1.24	1.37	2.02	3.30	4.55	5.80	6.41	7.64	8.86	8.86	7.43	5.89	4.54	3.45	2.74	2.24	1.60	1.22	0.97		
16	0.08	0.20	0.39	0.75	1.32	1.46	2.15	3.52	4.86	6.18	6.84	8.15	9.45	9.76	8.18	6.49	5.00	3.80	3.02	2.47	1.77	1.34			
17	0.09	0.21	0.41	0.80	1.40	1.55	2.29	3.74	5.16	6.57	7.27	8.66	10.04	10.69	8.96	7.11	5.48	4.17	3.31	2.71	1.94	1.47			
18	0.09	0.22	0.43	0.84	1.48	1.64	2.42	3.96	5.46	6.95	7.69	9.17	10.63	11.65	9.76	7.75	5.97	4.54	3.60	2.95	2.11	1.60			
19	0.10	0.24	0.46	0.89	1.57	1.73	2.56	4.18	5.77	7.34	8.12	9.68	11.22	12.64	10.59	8.40	6.47	4.92	3.91	3.20	2.29	0.09			
20	0.10	0.25	0.48	0.94	1.65	1.82	2.69	4.39	6.07	7.73	8.55	10.18	11.81	13.42	11.44	9.07	6.99	5.31	4.22	3.45	2.47				
21	0.11	0.26	0.51	0.98	1.73	1.91	2.83	4.61	6.37	8.11	8.98	10.69	12.40	14.10	12.30	9.76	7.52	5.72	4.54	3.71	2.66				
22	0.11	0.27	0.53	1.03	1.81	2.01	2.96	4.83	6.68	8.50	9.40	11.20	12.99	14.77	13.19	10.47	8.06	6.13	4.87	3.98	2.85				
23	0.12	0.28	0.55	1.08	1.90	2.10	3.10	5.05	6.98	8.89	9.83	11.71	13.58	15.44	14.10	11.19	8.62	6.55	5.20	4.26	3.05				
24	0.12	0.30	0.58	1.12	1.98	2.19	3.23	5.27	7.28	9.27	10.26	12.22	14.17	16.11	15.03	11.93	9.18	6.99	5.54	4.54	0.87				
25	0.13	0.31	0.60	1.17	2.06	2.28	3.36	5.49	7.59	9.66	10.69	12.73	14.76	16.78	15.98	12.68	9.76	7.43	5.89	4.82					
26	0.13	0.32	0.63	1.22	2.14	2.37	3.50	5.71	7.89	10.04	11.11	13.24	15.35	17.45	16.95	13.45	10.36	7.88	6.25	5.12					
28	0.14	0.35	0.67	1.31	2.31	2.55	3.77	6.15	8.50	10.82	11.97	14.26	16.53	18.79	18.94	15.03	11.57	8.80	6.99	5.72					
30	0.15	0.37	0.72	1.41	2.47	2.74	4.04	6.59	9.11	11.59	12.82	15.28	17.71	20.14	21.01	16.67	12.84	9.76	7.75	6.34					
32	0.16	0.40	0.77	1.50	2.64	2.92	4.31	7.03	9.71	12.36	13.68	16.30	18.89	21.48	23.14	18.37	14.14	10.76	8.54	1.41					
35	0.18	0.43	0.84	1.64	2.88	3.19	4.71	7.69	10.62	13.52	14.96	17.82	20.67	23.49	26.30	21.01	16.17	12.30	9.76						
40	0.21	0.50	0.96	1.87	3.30	3.65	5.38	8.79	12.14	15.45	17.10	20.37	23.62	26.85	30.06	25.67	19.76	15.03							
45	0.23	0.56	1.08	2.11	3.71	4.10	6.06	9.89	13.66	17.39	19.24	22.92	26.57	30.20	33.82	30.63	23.58	5.53							
	TYPE A LUBE				TYPE B LUBRICATION									TYPE C LUBRICATION											

A.7 Preferred sizes and Reynard (R-Series) Numbers

Table A–17

Preferred Sizes and Renard (R-Series) Numbers
(When a choice can be made, use one of these sizes; however, not all parts or items are available in all the sizes shown in the table.)

Fraction of Inches

$\frac{1}{64}$, $\frac{1}{32}$, $\frac{1}{16}$, $\frac{3}{32}$, $\frac{1}{8}$, $\frac{5}{32}$, $\frac{3}{16}$, $\frac{1}{4}$, $\frac{5}{16}$, $\frac{3}{8}$, $\frac{7}{16}$, $\frac{1}{2}$, $\frac{9}{16}$, $\frac{5}{8}$, $\frac{11}{16}$, $\frac{3}{4}$, $\frac{7}{8}$, 1, $1\frac{1}{4}$, $1\frac{1}{2}$, $1\frac{3}{4}$, 2, $2\frac{1}{4}$, $2\frac{1}{2}$, $2\frac{3}{4}$, 3, $3\frac{1}{4}$, $3\frac{1}{2}$, $3\frac{3}{4}$, 4, $4\frac{1}{4}$, $4\frac{1}{2}$, $4\frac{3}{4}$, 5, $5\frac{1}{4}$, $5\frac{1}{2}$, $5\frac{3}{4}$, 6, $6\frac{1}{2}$, 7, $7\frac{1}{2}$, 8, $8\frac{1}{2}$, 9, $9\frac{1}{2}$, 10, $10\frac{1}{2}$, 11, $11\frac{1}{2}$, 12, $12\frac{1}{2}$, 13, $13\frac{1}{2}$, 14, $14\frac{1}{2}$, 15, $15\frac{1}{2}$, 16, $16\frac{1}{2}$, 17, $17\frac{1}{2}$, 18, $18\frac{1}{2}$, 19, $19\frac{1}{2}$, 20

Decimal Inches

0.010, 0.012, 0.016, 0.020, 0.025, 0.032, 0.040, 0.05, 0.06, 0.08, 0.10, 0.12, 0.16, 0.20, 0.24, 0.30, 0.40, 0.50, 0.60, 0.80, 1.00, 1.20, 1.40, 1.60, 1.80, 2.0, 2.4, 2.6, 2.8, 3.0, 3.2, 3.4, 3.6, 3.8, 4.0, 4.2, 4.4, 4.6, 4.8, 5.0, 5.2, 5.4, 5.6, 5.8, 6.0, 7.0, 7.5, 8.5, 9.0, 9.5, 10.0, 10.5, 11.0, 11.5, 12.0, 12.5, 13.0, 13.5, 14.0, 14.5, 15.0, 15.5, 16.0, 16.5, 17.0, 17.5, 18.0, 18.5, 19.0, 19.5, 20

Millimeters

0.05, 0.06, 0.08, 0.10, 0.12, 0.16, 0.20, 0.25, 0.30, 0.40, 0.50, 0.60, 0.70, 0.80, 0.90, 1.0, 1.1, 1.2, 1.4, 1.5, 1.6, 1.8, 2.0, 2.2, 2.5, 2.8, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, 8.0, 9.0, 10, 11, 12, 14, 16, 18, 20, 22, 25, 28, 30, 32, 35, 40, 45, 50, 60, 80, 100, 120, 140, 160, 180, 200, 250, 300

Renard Numbers*

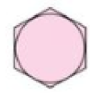
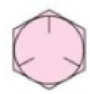
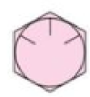
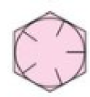
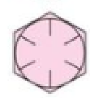
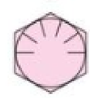
1st choice, R5: 1, 1.6, 2.5, 4, 6.3, 10
2d choice, R10: 1.25, 2, 3.15, 5, 8
3d choice, R20: 1.12, 1.4, 1.8, 2.24, 2.8, 3.55, 4.5, 5.6, 7.1, 9
4th choice, R40: 1.06, 1.18, 1.32, 1.5, 1.7, 1.9, 2.12, 2.36, 2.65, 3, 3.35, 3.75, 4.25, 4.75, 5.3, 6, 6.7, 7.5, 8.5, 9.5

*May be multiplied or divided by powers of 10.

A.8 Specifications for steel Bolts

Table 8-9

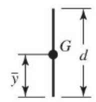
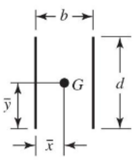
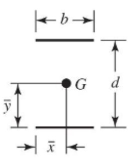
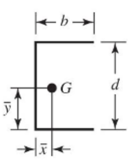
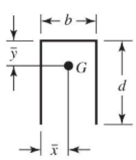
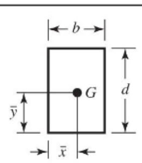
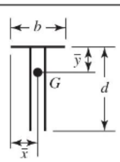
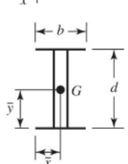
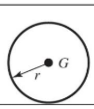
SAE Specification for steel Bolt

SAE Grade No.	Size Range Inclusive, in	Minimum Proof Strength,* kpsi	Minimum Tensile Strength,* kpsi	Minimum Yield Strength,* kpsi	Material	Head Marking
1	$\frac{1}{4}$–$1\frac{1}{2}$	33	60	36	Low or medium carbon	
2	$\frac{1}{4}$–$\frac{3}{4}$	55	74	57	Low or medium carbon	
	$\frac{7}{8}$–$1\frac{1}{2}$	33	60	36		
4	$\frac{1}{4}$–$1\frac{1}{2}$	65	115	100	Medium carbon, cold-drawn	
5	$\frac{1}{4}$–1	85	120	92	Medium carbon, Q&T	
	$1\frac{1}{8}$–$1\frac{1}{2}$	74	105	81		
5.2	$\frac{1}{4}$–1	85	120	92	Low-carbon martensite, Q&T	
7	$\frac{1}{4}$–$1\frac{1}{2}$	105	133	115	Medium-carbon alloy, Q&T	
8	$\frac{1}{4}$–$1\frac{1}{2}$	120	150	130	Medium-carbon alloy, Q&T	
8.2	$\frac{1}{4}$–1	120	150	130	Low-carbon martensite, Q&T	

A.9 Bending Properties of Fillet Welds

Table 9-2

Bending Prosperities of Fillet Welds

Weld	Throat Area	Location of G	Unit Second Moment of Area
1. 	$A = 0.707hd$	$\bar{x} = 0$ $\bar{y} = d/2$	$I_u = \frac{d^3}{12}$
2. 	$A = 1.414hd$	$\bar{x} = b/2$ $\bar{y} = d/2$	$I_u = \frac{d^3}{6}$
3. 	$A = 1.414hb$	$\bar{x} = b/2$ $\bar{y} = d/2$	$I_u = \frac{bd^2}{2}$
4. 	$A = 0.707h(2b + d)$	$\bar{x} = \frac{b^2}{2b+d}$ $\bar{y} = d/2$	$I_u = \frac{d^2}{12}(6b+d)$
5. 	$A = 0.707h(b + 2d)$	$\bar{x} = b/2$ $\bar{y} = \frac{d^2}{b+2d}$	$I_u = \frac{2d^3}{3} - 2d^2\bar{y} + (b+2d)\bar{y}^2$
6. 	$A = 1.414h(b + d)$	$\bar{x} = b/2$ $\bar{y} = d/2$	$I_u = \frac{d^2}{6}(3b+d)$
7. 	$A = 0.707h(b + 2d)$	$\bar{x} = b/2$ $\bar{y} = \frac{d^2}{b+2d}$	$I_u = \frac{2d^3}{3} - 2d^2\bar{y} + (b+2d)\bar{y}^2$
8. 	$A = 1.414h(b + d)$	$\bar{x} = b/2$ $\bar{y} = d/2$	$I_u = \frac{d^2}{6}(3b+d)$
9. 	$A = 1.414\pi hr$		$I_u = \pi r^3$

References

[1] Meineke, “No Title.” [Online]. Available: https://www.meineke.com/blog/properly-wash-car/.

[2] Wikipedia, “No Title.” [Online]. Available: https://www.wikipedia.org/.

[3] Ourwarwickshire, “No Title.” [Online]. Available: https://www.ourwarwickshire.org.uk/content/catalogue_wow/leamington-spa-carriage-in-courtyard-of-raford-cottage.

[4] Galeon, “No Title.” [Online]. Available: http://autolavaggibellucci.galeon.com/100-Years-of-Car-Wash.html.

[5] Propaintwa, “No Title.” [Online]. Available: https://propaintwa.com.au/wp-content/uploads/2016/09/car-wash.jpg.

[6] Theroyalwash, “No Title.” [Online]. Available: http://www.theroyalwash.com/wp-content/themes/accelerate/images/level3_image.jpg.

[7] Mjcarwash, “No Title.” [Online]. Available: https://www.mjcarwash.com/man-versus-machine-better-car-washing/.

[8] Auto-repair-equipment, “No Title.” [Online]. Available: http://www.auto-repair-equipment.com/vehicle-wash-machine/car-wash-machine/ce-gantry-car-washing-machine.html%0A%0A.

[9] Turnkeycarwash, “No Title.” [Online]. Available: http://www.turnkeycarwash.com/carwash-products/carwash-chemicals/.

[10] Leiseues, “No Title.” [Online]. Available: http://carwashtouchless.com/.

[11] Carwashtouchless, “No Title.” [Online]. Available: http://carwashtouchless.com/product/leisuwash-leibao-360-automatic-vehicle-wash-system/.

[12] Alibaba, “No Title.” [Online]. Available: https://www.alibaba.com/showroom/laser-wash-360.html.

[13] Dhgate, “No Title.” [Online]. Available: https://www.dhgate.com/product/1-4-stainless-steel-6504-flat-fan-spray-nozzle/412795202.html.

[14] Mechafile, “No Title.” [Online]. Available: http://www.mechafile.ir/item/محور-انتقال-قدرت/.

[15] Alibaba, “No Title.” [Online]. Available: https://www.alibaba.com/showroom/small-wheels.html.

[16] Ritbearing, “No Title.” [Online]. Available: https://www.ritbearing.com/.

[17] Monotaro, “No Title.” [Online]. Available: https://www.monotaro.sg/g/00869431/.

[18] Grabcad, “No Title.” [Online]. Available: https://grabcad.com/library/t10x440-toothed-belt.

[19] Reliabilitydirectstore, “No Title.” [Online]. Available: https://www.reliabilitydirectstore.com/SKF-TKBA-40-BeltAlign-Belt-Alignment-Tool-p/skf-tkba-40.htm.

[20] Vventerprises163, “No Title.” [Online]. Available: https://www.vventerprises163.com/panel-air-conditioner-fanmotor.html.

[21] Aliexpress, “No Title.” [Online]. Available: https://www.aliexpress.com/item/Delta-AC-Servo-Motor-B2-Series-ECMA-C20807RS-80mm-220V-3000rpm-keyway-Oil-Seal-750W-New/817772830.html.

[22] Technoteka, “No Title.” [Online]. Available: https://technoteka.com.ua/p/poverhnostnyj-nasos-speroni-cb-203b-trehfaznyj-101102620.

[23] Electricalmantra, “No Title.” [Online]. Available: http://electricalmantra.com/phase-

sequence-relay/.
[24] Inverterdrive, “No Title.” [Online]. Available: https://inverterdrive.com/group/AC-Inverter-Drives-230V/Schneider-ATV31H075M2/.
[25] Reviewmotors, “No Title.” [Online]. Available: https://reviewmotors.co/tiga-contoh-alat-yang-memanfaatkan-motor-listrik/.
[26] Grainger, “No Title.” [Online]. Available: https://www.grainger.com.mx/producto/SCHNEIDER-ELECTRIC-Contacto-Magnético-IEC%2C32A%2CPolos3%2C240VCA/p/3DY54.
[27] Hepsiburada, “No Title.” [Online]. Available: https://www.hepsiburada.com/schneider-electric-lrd03-termik-role-0-25-0-40a-pm-HB00000EZS06.
[28] Nutree, “No Title.” [Online]. Available: http://10.nutree.autofit-wrohm.de/dac/wiring-diagram-for-motor-starter.html.
[29] Pepperl-fuchs, “No Title.” [Online]. Available: https://www.pepperl-fuchs.com/global/en/classid_fa.htm?view=productdetails&prodid=46535.
[30] Robotshop, “No Title.” [Online]. Available: https://www.robotshop.com/en/micro-contact-limit-switch.html%0A%0A.
[31] Madeagleband, “No Title.” [Online]. Available: http://7.kawen.madeagleband.de/tyi/vfd-wiring-schematic.html.
[32] Megawavz, “No Title.” [Online]. Available: https://megawavz.com/shop/schneider-electric-twido-programmable-logic-controller/.
[33] skf, “No Title.” [Online]. Available: www.skf.com.
[34] Themechanicalengineer, “No Title.” [Online]. Available: http://themechanicalengineer.com/engineering/design-analysis/bolted-joints/bolt-strength-strength-of-fasteners/shear-capacity/.
[35] Autofem, “No Title.” [Online]. Available: https://autofem.com/en/autofem-products/autofem-buckling-analysis.html.
[36] Byjus, “No Title.” [Online]. Available: https://byjus.com/physics/angular-acceleration/.