1. INTRODUCTION

1.1. Background

Compound preparation is still a manual process in glove manufacturing industry, because it requires close supervision and skill for achieving required quality of compound. Quality compound is essential to gain required physical and mechanical properties of a specific glove. In this case adhere to correct formulation is also important.

In this manual process weighing of each chemical precisely and mixing them in a specific time is essential. Also in this process human interference is very high and this is a monotonous work too. Furthermore there are specific compound formulations among competitive companies which are to be kept securely without revealing to others. Therefore there’s a necessity of minimizing human intervention in compounding and automating the process while mimicking the human skill.

1.2. Characteristic of the existing system

In existing compound preparation process NBR and other required chemicals are pre weighed and mixed one by one with NBR in specific time durations allowing better chemical reactions. Each chemical is weighed manually according to the formulation. Below are the characteristic points of this system.

- NBR and 15 to 18 other chemicals are used depending on compound type
- Chemical viscosities are vary (1-25poise)
- Quantities of chemicals vary within a considerable range in a single batch size (e.g.- 800g to16kg)
- Chemicals should be pre weighed
- Should be mixed one after the other according to the formulation
- Should be mixed within a specific time and specific speed

1.3. Literature Review

There's no fully automated compounding machine in glove industry, but similar machines, research and developments can be found in other industries. Those machines cannot be adapted to glove compounding due to some limitations. Three similar R & D reports were referred and reviewed in this research. All three researches have been done for mixing several liquids which have almost same viscosity levels and purposes were to measure required quantities from each liquid and mixing them together. Below are the three research topics.

1. Design and Development of an Automated Paint Mixing Machine.
2. An Automated Microcontroller-based Cocktail Mixer And Dispenser
3. Automatic Paint Mixing Process Using Lab view (software)

1.3.1. Design and Development of an Automated Paint Mixing Machine [1]

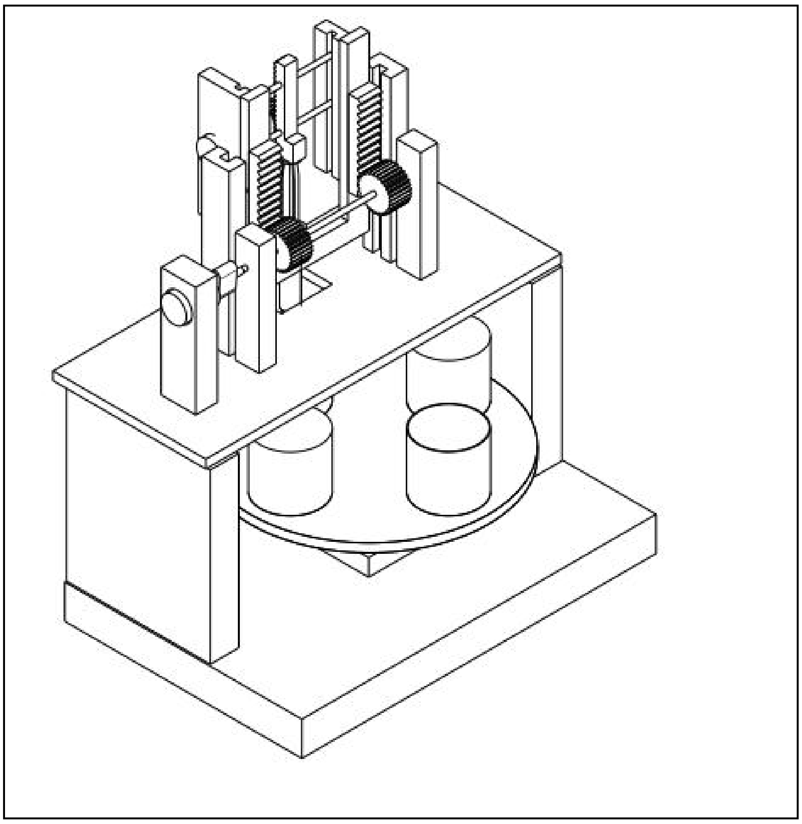


Fig 1.1 Automated Paint Mixing Machine [1].

The mechanical system of this paint mixing machine comprises of a rotary color holder which is rotated by a high torque motor, a color suction and pouring syringe which is pushed and pulled by a stepper motor driven rack and pinion mechanism and a syringe dipping and lifting rack and pinion mechanism which is also driven by a stepper motor. The rotary color holder consists of three RGB color chambers and a mixing chamber.

The control system comprises of an Arduino ADK controller, a color sensor, two stepper motors for driving the two rack and pinion mechanisms and a high torque motor for rotating the color holder and at the same time mixing the colors in the mixing chamber.

The color sensor measures the shade chromaticity of encompassing light or the color of articles and the digitized signal is fed to the controller. The controller drive motors accordingly to pick required amount of RGB colors and mix in the mixing chamber.

This concept or part of the mechanical and control systems can be taken in to consideration for the automated compound preparation task.

1.3.2. Automated Microcontroller-based Cocktail Mixer and Dispenser [3]

Fig 1.2 Automated Cocktail Mixer and Dispenser [3]

Basically this machine consists of five sections. They are display and data entering module, PIC micro controllers (three controllers), 7 Dispensers, Stirrer and the Mixing container.

Out of seven dispensers six contain ingredients for cocktail and the other contains water solely for rinsing purpose. This each dispenser consists of a submersible pump and a level sensor. The dispensed ingredients to the mixing container are mixed by a DC motor controlled stirrer and the final product in mixing container is released by a servo motor controlled valve attached to the mixing container.

In case of control part three PIC controllers are used for specific purposes. The first PIC controller receives data entering through the data entering module and delivers them to the second PIC controller which is basically functions as a storage and also it has been programed to display error signals via display unit. The third PIC controller responsible for controlling all the dispensing and mixing process done by the machine.

1.3.3. Automatic Paint Mixing Process Using Lab view software [2]

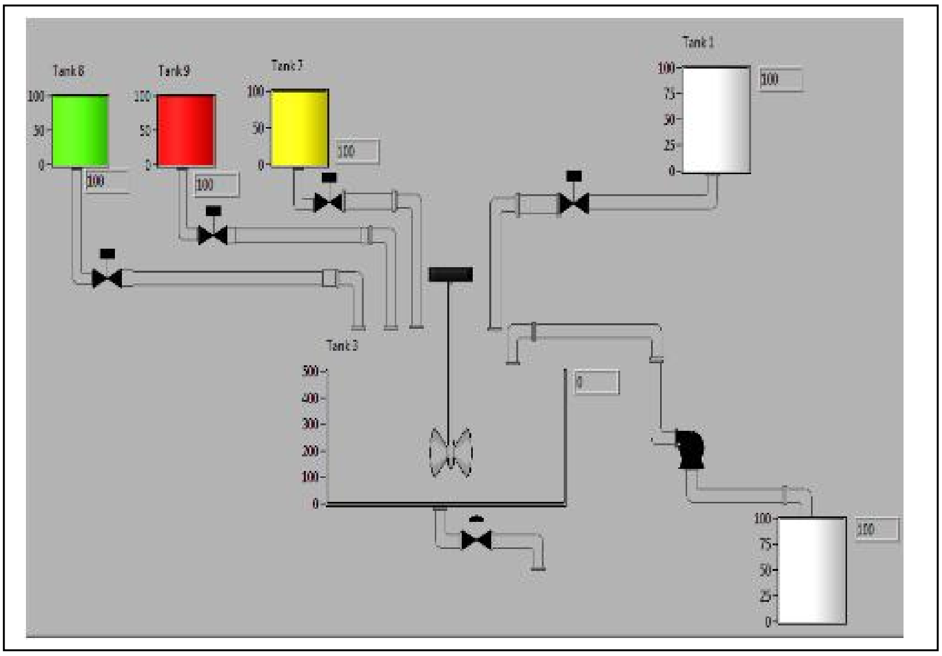


Fig 1.3 Automatic Paint Mixing Machine in Lab View Environment [2]

The automatic paint mixing machine has been designed and implemented in the LabVIEW environment (Software).As illustrated in Fig-3 the system consists of four paint tanks green, red, yellow and white colors. Each tank is connected to a mixing tank through pipe lines and also each consists of solenoid valves.Thedesired or specified quantity of raw material (white paint) can be controlled by adjusting the opening time of the solenoid valve, and then the new color can be prepared by adjusting the duration of the opening of the three solenoid valves for the three tinctures. After feeding, the mixer will turn ON to mix and to achieve good construction of the new color. Then the solenoid valve at mixing tank will be opened to take the new color out. After that, the cleaner liquid in tank will be pumped to the mixer tank to clean the inner surface of the mixing tank.

A front panel (graphic user interface GUI) has been designed to assist the user in how to feed the required amount of tincture to produce the specified color. It also provides the user with information about the state of tincture control valves and the availability of the tinctures in the tanks as well as the raw material tanks.

1.3.4. Comparison of Researches.

From all three papers below important points are analyzed and this may be considered and adopted in compounding process.

- Requirement of the research.
- Type of the liquid.
- Number of liquids handled.
- Measuring technique.
- Mixing procedure.
- Control technique.

Above points relevant to each project can be summarized as below.

	Requirement	**Liquid Type**	**No of Liquids**	**Measuring technique**	**Mixing procedure**	**Control technique**
1	Detection of desired color & Regeneration it precisely Avoid exposure to harmful toxins Further improvements for spray painting	Same viscous fluids	3 liquid paints (R,G,B)	Suction syringe driven by rack and pinion mechanism coupled with a stepper motor	Picking up correct amount of each color Pour in to the mixing vessel Mixed by a high torque agitator No sequence required	ARDUINO ADK Controller based stepper motor drive system, Color sensor
2	Easy and efficient method with minimal human intervention Avoid mistakes	Same viscous fluids	7 Liquids	Submersible pumps and level sensors	All six ingredients dispensed to mixing container at the same time and mixed by DC motor driven stirrer (spoon)	Three microcontroller based system
3	To replace the manual paint composition method to meet the required color	Same viscous fluids	4 Liquid paints	Opening solenoid valves with a specific time delay	Add white paint Then add other colors as desired to mixing container and mixing	Software algorithm(Lab View) to control solenoid valve opening time

Table 1.1 Comparison of significant points of three researches

Above important points need to be considered in automating the compounding process. This can be adapted to compounding process as below.

	Requirement	Liquid Type	No of Liquids	Measuring technique	Mixing procedure	Control technique
Glove Compounding(which is to be automated)	Maintaining the secrecy of compound formulation Easy and efficient operation Minimal human intervention Avoid exposure to harmful toxins Avoid mistakes Maintaining consistent quality	Different viscosities (vary within a considerable range) 1-25poise	15 to 18 liquids used in a single batch	Available techniques Gravity feeding with time delay Suction by a piston and control the piston stroke Pumping and metering Pumping and weighing	Mixing sequence Weighing NBR Add other chemicals one by one in a specific time while mixing Mixing impeller speeds should be vary according to the adding chemical	Reliable controllers which is suitable for industrial environment Easily replaceable Easy human machine interface

Table 1.2 Relevant significant points in Table-1 compared with the compounding process to be automated

1.3.5. Reviewing of some more researches

In case of this research chemical measuring and chemical feeding techniques are very important, because in compound preparation measuring correct amount of chemicals is essential and also when feeding chemicals to mixing chamber it is necessary to maintain the required flow rate. That is to mix each chemical in a specific time. Considering these points below papers were reviewed.

1. Weight based liquid filling using PLC and HMI
2. Controlling Flow Rate and Fluid Level by Variable Frequency Drive Unit.
3. Methods of Fluid Level Measurement in Industrial Processes.

Weight based liquid filling using PLC and HMI [4]

In this paper it talks about the liquid filled in the bottles in small scale industries. Here it is proposed to automate the manual filling process. In this manual process bottles are filled manually according to the weight. Also in this case accuracy is a problem due to overfilling or under filling. Therefore to overcome this problem the system is automated by considering the same scenario. That is to measure the weight of the bottle automatically while filling. This system comprises of a PLC, HMI unit, solenoid valve, load cell and a signal amplifier. The load cell signal proportionate to the weight is amplified via the signal conditioner and fed to the PLC and accordingly PLC controls the opening and closing of the solenoid valve attached to the liquid container. The required weight is entered by the operator via HMI unit connected to the PLC.

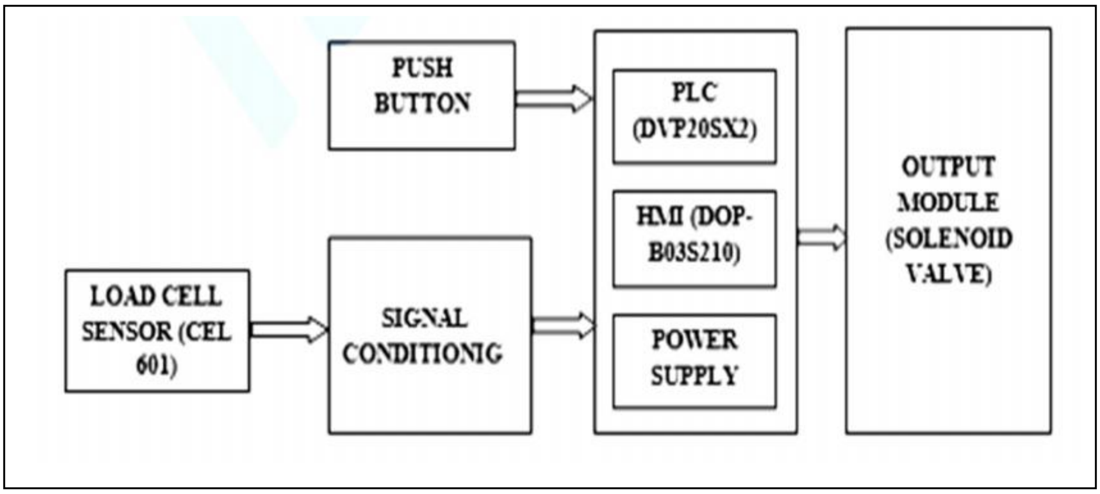


Fig 1.4 Block diagram of the weight based liquid filling System [4]

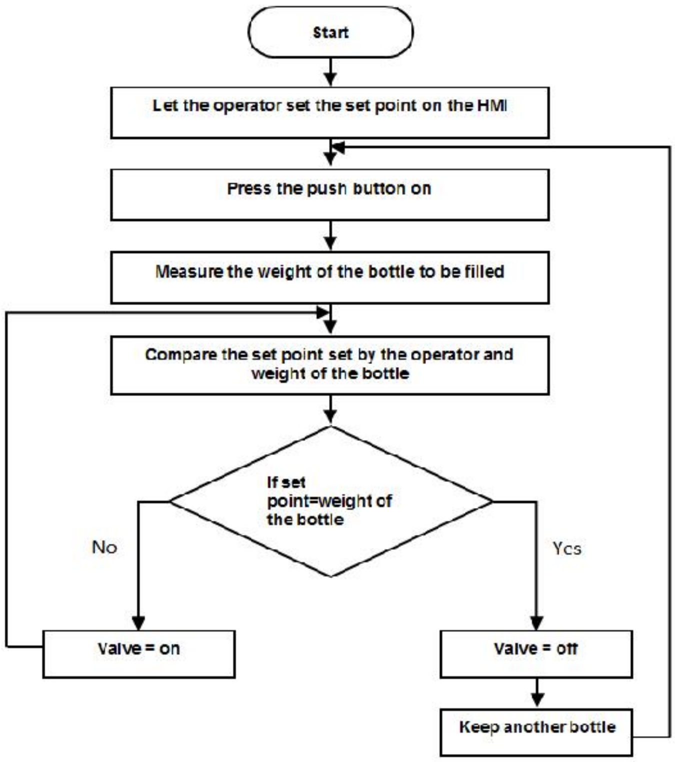


Fig 1.5 Flow chart of the weight based liquid filling process [4]

This methodology also can be considered in measuring correct amount of chemicals in automated compounding process.

Controlling Flow Rate and Fluid Level by Variable Frequency Drive Unit [5]

According to this paper in flow loads applications like pumps, compressors, fans and blowers constant speed A.C electrical motors are widely used. In most of these applications the output flow is controlled by throttling or restrictive devices. Sometimes mechanical speed changers and recirculation systems are also used. In all of these systems energy is wasting when controlling the flow.

In this paper it discusses about introducing of variable frequency devices (VFD) for pumping systems. Using a VFD in pump controlling also eliminating additional elements required in valve controlled systems and hence reduced power and cost.

In case of close loop systems flow meters and pressure transmitters can be used as feedback devices.

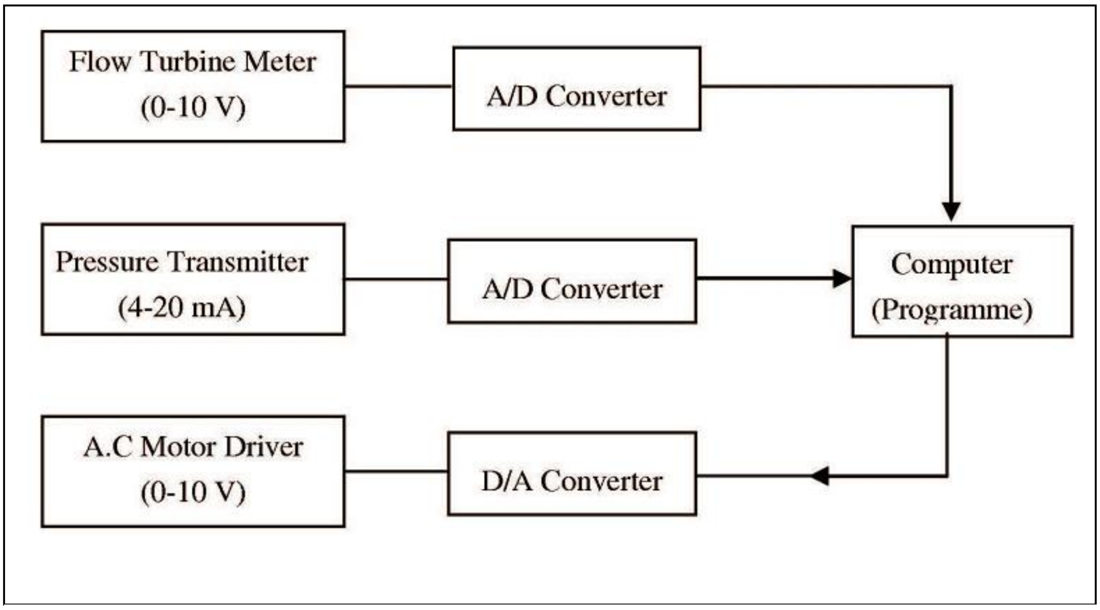


Fig 1.6 Control operation block diagram [5]

Methods of Fluid Level Measurement in Industrial Processes [6]

Liquid level measurement techniques are also important in measuring the required amount of liquids in industrial processes. Here in this paper it talks about liquid level measurement techniques ranges from simple less accurate systems to accurate latest systems. All liquid level techniques talked in this paper can be summarized as in the Table- 1.3.

In case of automating of compounding process measuring the chemicals by weight is important and reliable since in manual process it has been practiced and proven for all types of chemicals used. Since the density of the chemicals vary with the temperature and some are foam liquids by measuring the liquid level, correct weight of the chemical may not be taken. Therefore except the load cells other level measuring techniques mentioned in the Table 1.3 can not be used for this task.

	Liquid level Measuring Technique	Advantages	Disadvantages
1	Glass level Gauge	Simplest method	Glass can be failed catastrophically
		Clear visibility	Leakage problems
2	Floats	comprises with mechanical arrangements like pulleys,tapes,gears and cables	Bulky systems
		reliable	
		continuous measurements	
3	Hydrostatic devices.		
	Displacers, Bubblers, Differential pressure transmitters	Analog signals	due to changes in temperature specific gravity of liquid changes and hence reduced accuracy
4	Load cell	Accurate measurement	
		wide range of measurement(from ounces to tons)	noncontact supporting structures need to be designed
			besides the net liquid weight structure weight is collectively measured
5	Magnetic level gauges	replacement for sight glass	to work the system chamber walls should be non magnetic materials
6	Capacitance transmitters	continuous level measurement	
7	ultrasonic level transmitters	quick measurements since the operational frequency is high(tens of kilohertz)	sound speed vary with temperature
8	laser level transmitter	precise measurement	
		can be directed through small spaces	
9	radar level transmitter	can be work in a vacuum	pressure and temperature affects the speed
		even foam layers can be measured	

Table 1.3 Advantages and disadvantages of liquid level measuring techniques

1.4. Problem Statement

Since compounding requires high skilled labor human interference is high. Even though this is essential in quality compounding this will badly affect both for human health and company technology since the secrecy of technology may revealed to competitors. Therefore an automated compounding machine need to be introduced while mimicking the human skill.

When Table-1.1 and Table-1.2 are compared we can conclude that no machine addresses below factors simultaneously.

- Handling 15 to 18 chemicals
- Handling different viscosity chemicals
- Considerable variation of chemical quantities which are to be measured
- Each chemical should be mixed within a specific time
- Chemicals should be mixed one after the other
- Variable mixing speeds

Below factors also should be highly concerned.

- Maintaining the secrecy of compound formulation.
- Easy and efficient operation.
- Minimal human intervention.
- Avoid exposure to harmful toxins.
- Avoid mistakes.
- Maintaining consistent quality.

Therefore there is requirement and vital importance of finding a solution for automated compounding method for glove industry. A specific machine should be fabricated by considering whole factors.

1.5. Objectives of the Study

There are four major objectives to be achieved from this task.

- Measuring the required amount of chemicals precisely by one of the methods mentioned in Table-1.2
- Mixing each chemical one after the other during a specific time.
- Introducing an easy operator machine interface.
- Maintaining the secrecy of the compound formulation and minimizing the interference of human in compound technology.
-

1.6.Methodology

1.6.1. Measuring Technique

To fulfill the first objective mentioned above a suitable chemical measuring technique should be selected. When comparing the measuring techniques from Table-2 Gravitational feeding method and sucking chemicals by a piston cylinder are difficult in this case, because some are foam type chemicals and some are sticky. Therefore remaining two methods were considered.

Two trials were done for below methods.

- Metering
- Weighing

Trial 1-Metering

In this case tried to maintain a constant flow rate by controlling the rpm of servo pump. A special non drip valve was fabricated and used for avoiding the dripping of chemicals.

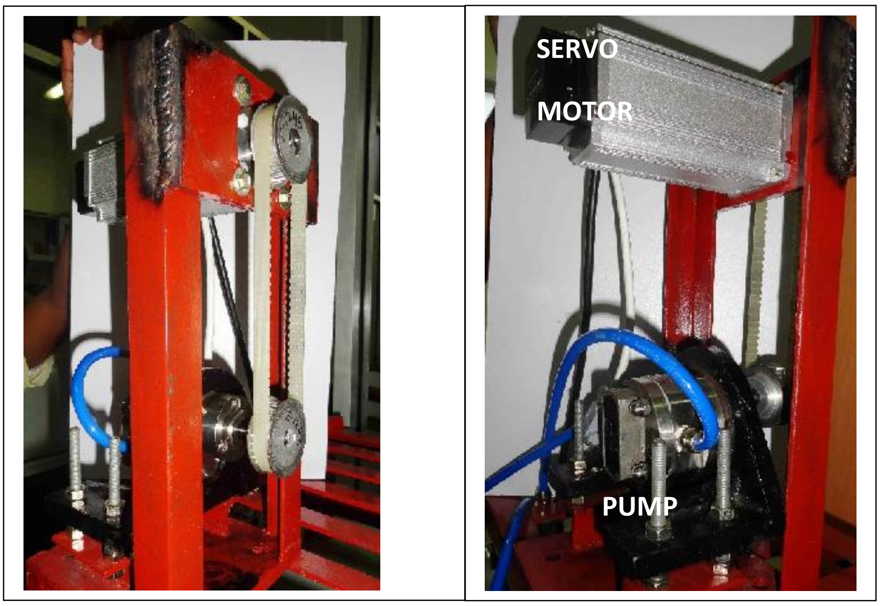


Fig 1.7 Pump and servo motor arrangement used in trial

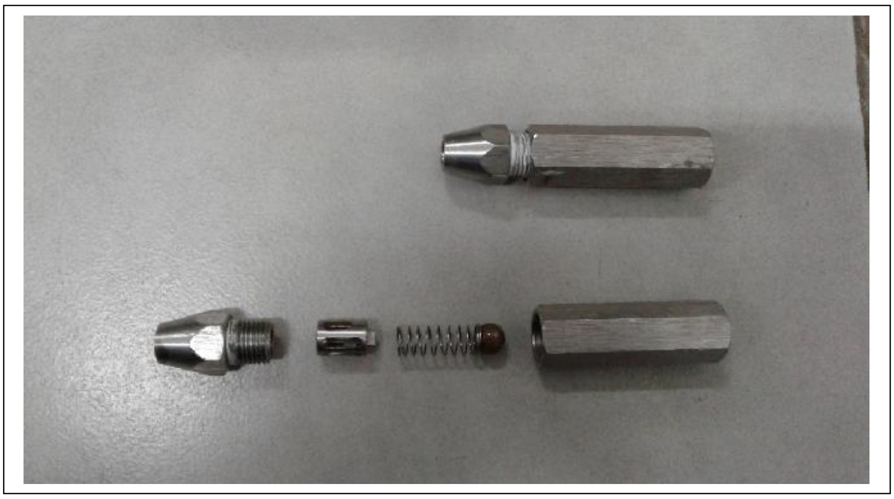


Fig 1.8 Non drip valve

This method was not accurate enough and readings varied time to time due to use of different viscous fluids. (Volatile liquids, dispersions, thick liquids, foam liquids). Also the viscosities may vary with batch wise, with temperature and with time.

Furthermore it was hard to maintain same pressure due to clogging of valve. Therefore this method was failed.

Trial 2-Weighing

In this case required weight of the chemical is considered. This system consists of a load cell, a load cell signal amplifier, servo pump and a PLC with a analog module. The load cell signal is amplified by the load cell amplifier and fed to the PLC analog module. The servo pump is operated and stopped according to the analog signal. Also a solenoid valve is fixed at the pump delivery line for avoiding the chemical dripping. This is also operated according to the PLC signal.

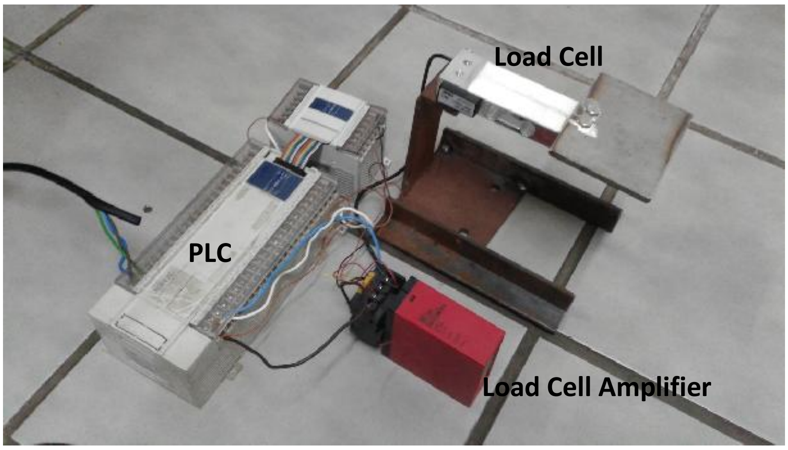


Fig 1.9 Chemical weighing arrangement used in the trial

For avoiding the chemical dripping problem several solenoid valves were tested and finally pinch valve type solenoid valve was selected. With compared to the other valves this valve is chemical resistant and zero clogging.

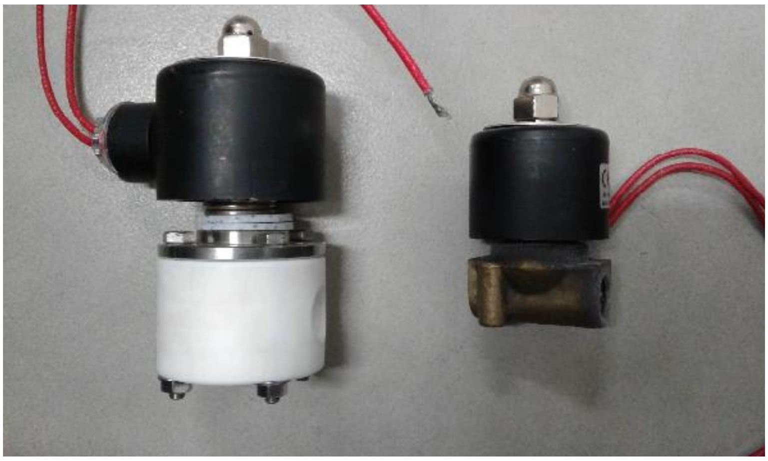


Fig1.10Solenoid valves used in test

Fig 1.11 Non drip pinch valve

Ultimately measuring the required amount of chemical precisely is done by means of a gear pump driven by a servo motor. The servo motor control signal is getting from the PLC unit. The PLC unit gets the feedback signal from the load cell via the load cell amplifier and drives the servo motor accordingly until the required weight is achieved. The solenoid valve operates simultaneously via a PLC relay output with the servo motor operation. There are altogether 18 chemical storage tanks equally mounted(9at left side,9at right side) at left and right sides and each tank has a pipe work through a gear pump and ends up at a common collecting tank at each side(left and right). These two collecting tanks are hanged on a two load cells. Furthermore there are two servo motor operated gear pumps attached to these two tanks. The 18 gear pumps are driven one at a time by common shaft driven by the servo motor. Each pump is engaged with the common shaft through electromagnetic clutches.

1.6.2. Mixing Technique

To achieve the second objective that is to mix the measured chemical in a specific time, the feeding flow rate should be maintained constant. According to the specified mixing time and the weight of each chemical the required flow rate is calculated by means of the PLC algorithm and this flow rate is maintained constant by means of the servo pump operated according to the load cell feedback. In this case PLC programming part is very important.

1.6.3. Operator Machine Interface

To achieve this objective mainly a programmable touch panel is used which is compatible with the PLC. By using this three main tasks to be achieved which help for easy operation.

- To enter and store required parametric values for each compound types and batch sizes.
- To monitor the process.
- To run the machine easily via the touch panel.

Also mechanical switches will be provided on the panel board for manual operation.

Fig1.12 Xinje XC3-60RT-E PLC and Xinje TH765-N HMI unit

1.6.4. Automation and Minimizing Human Intervention

Operator can be simply guided for selecting required compound types rather than deeply going in to chemical formula details by programming the touch panel.

Passwords can be programmed for different levels of users and secure the secret information.

2.0. DESIGN

2.1. System Identification

It can be identified three main systems by considering the overall system.

1. Chemical Filling System.
2. Chemical Weighing and Feeding System.
3. Chemical Mixing System.

Except the mixing head other systems are divided as Left and Right sides to maintain the sequence of operation. That is while one chemical is measured at one side previously measured chemical at the other side is feeding and mixing with NBR. This sequence is followed until all the chemicals are measured and mixed with NBR.

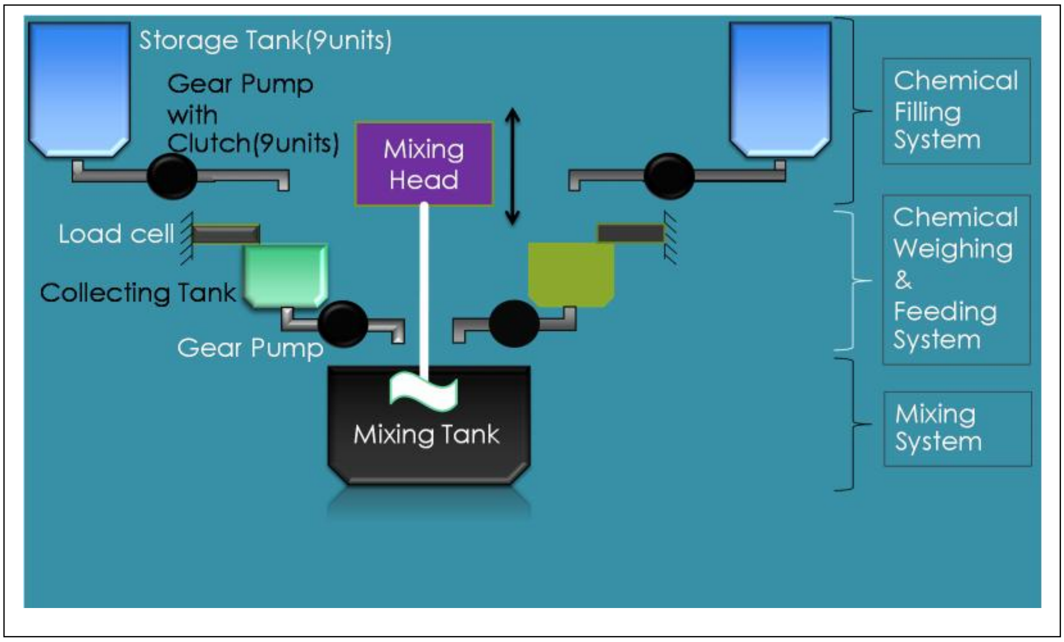


Fig 2.1 Overall System

2.1.1. Chemical Filling System.

This system consists of Chemical Storage, Chemical Pumping section and chemical weighing and collecting section. Altogether there are nine storage tanks at one side (Left and Right). There are nine gear pumps at each side connected with each storage tank and ends up at the collecting tanks at each side. These pumps are coupled to a single shaft via electromagnetic clutches and the shaft is driven by a servo motor. Each pump is operated by engaging the pump and the drive shaft by means of the clutch.

2.1.2. Chemical Weighing and Feeding System.

Two collecting tanks at both sides are hanged on load cells for measuring the required amount of chemicals when filling. Also two gear pumps are attached to each collecting tank for feeding the chemical to the mixing tank. Feeding chemical at a constant flow rate within a specific time is controlled by the PLC unit according to the feedback signal of the load cell. Therefore the weighing system is used both in chemical filling and chemical feeding to the mixing tank.

2.1.3. Chemical Mixing System.

This system consists of vertically movable mixing head which is driven by a three phase induction motor and gearbox arrangement, and a mixing impeller driven by a VSD controlled three phase induction motor and pulley arrangement. The impeller speed should be varied as specified for each chemical and it is done by a PLC analog signal given to the VSD. The overall process of the machine can be simplified as in Fig 2.2

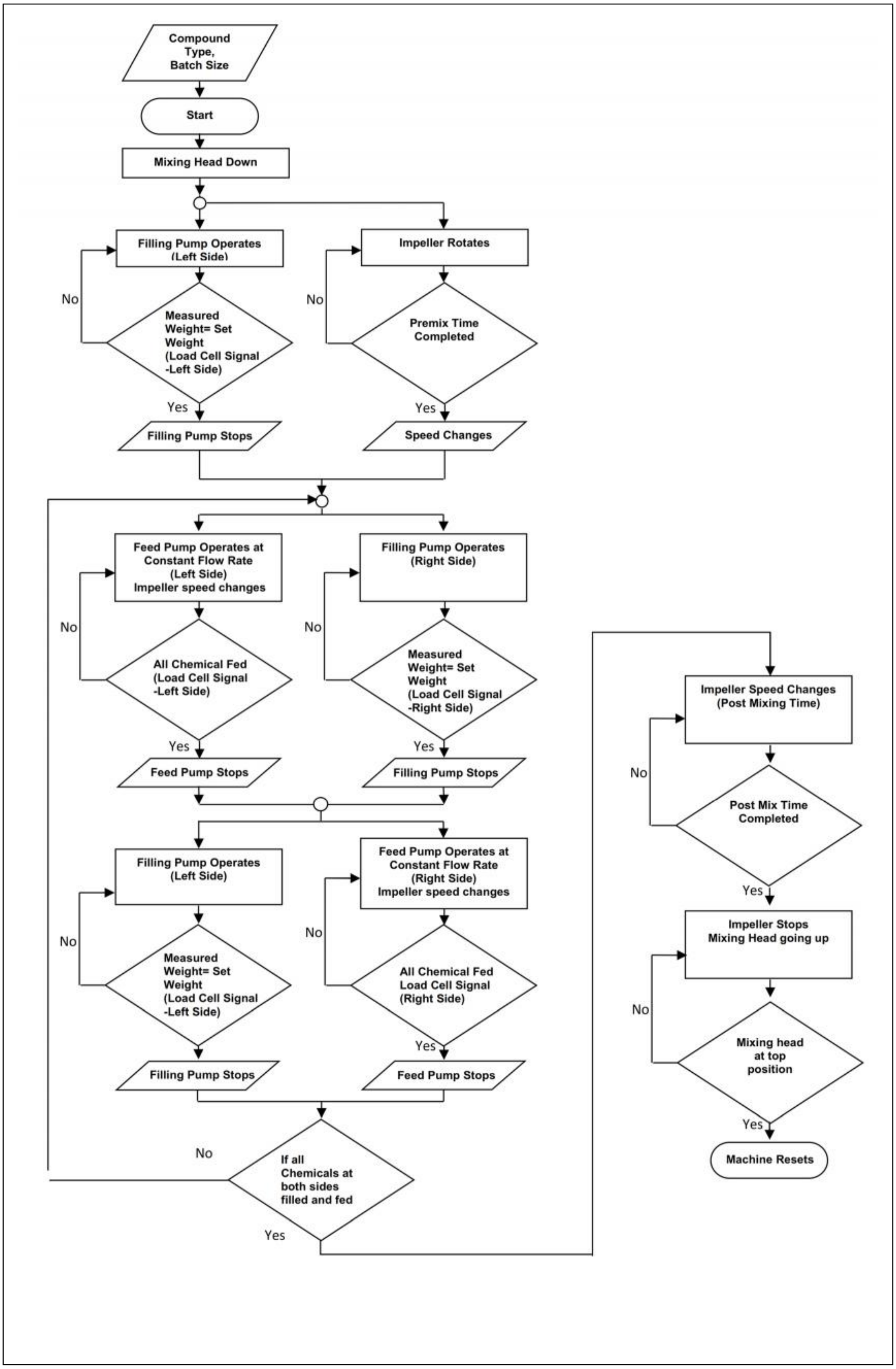


Fig 2.2 System flow chart

According to the flow chart for operating the machine first compound type and the batch size need to be selected. Then after pressing the start button the mixing head (impeller) comes down such a way that the impeller inserted to the mixing tank. After that two actions start parallel. One is the impeller start to rotate and the other one is the first filling pump at the left side starts filling the first chemical to the left side intermediate tank. After filling the required amount of chemical the filling pump stops and after the premix times the impeller speed changes according to the preset speed value relevant for the first chemical. After completing the above both actions, the left side feeding pump starts to feed the filled chemical at intermediate tank to the mixing tank while the right side first filling pump starts to fill the correct amount of second chemical into the right side intermediate tank. The filling pump stops after filling the correct amount of chemical to right side intermediate tank and the left side feeding pump stops after feeding all chemical within the specified time. When both of these actions finished the 3^{rd} chemical at left side is filled to the left side intermediate tank while right side feeding pump starts to release the filled chemical at right side intermediate tank into the mixing chamber and the impeller speed is also changed according to the set value. This sequence of chemical filling and feeding operations continues until all the set chemicals are fed to the mixing chamber. After mixing all the chemicals the impeller speed changes to the post mix speed value and runs for the preset post mix time. Finally the impeller stops and the mixing head goes up to its initial position. After all these operations the machine is reset and ready for the next compound preparation.

According to the identified systems and the process of the machine the overall control system can be illustrated as in Fig 2.3.

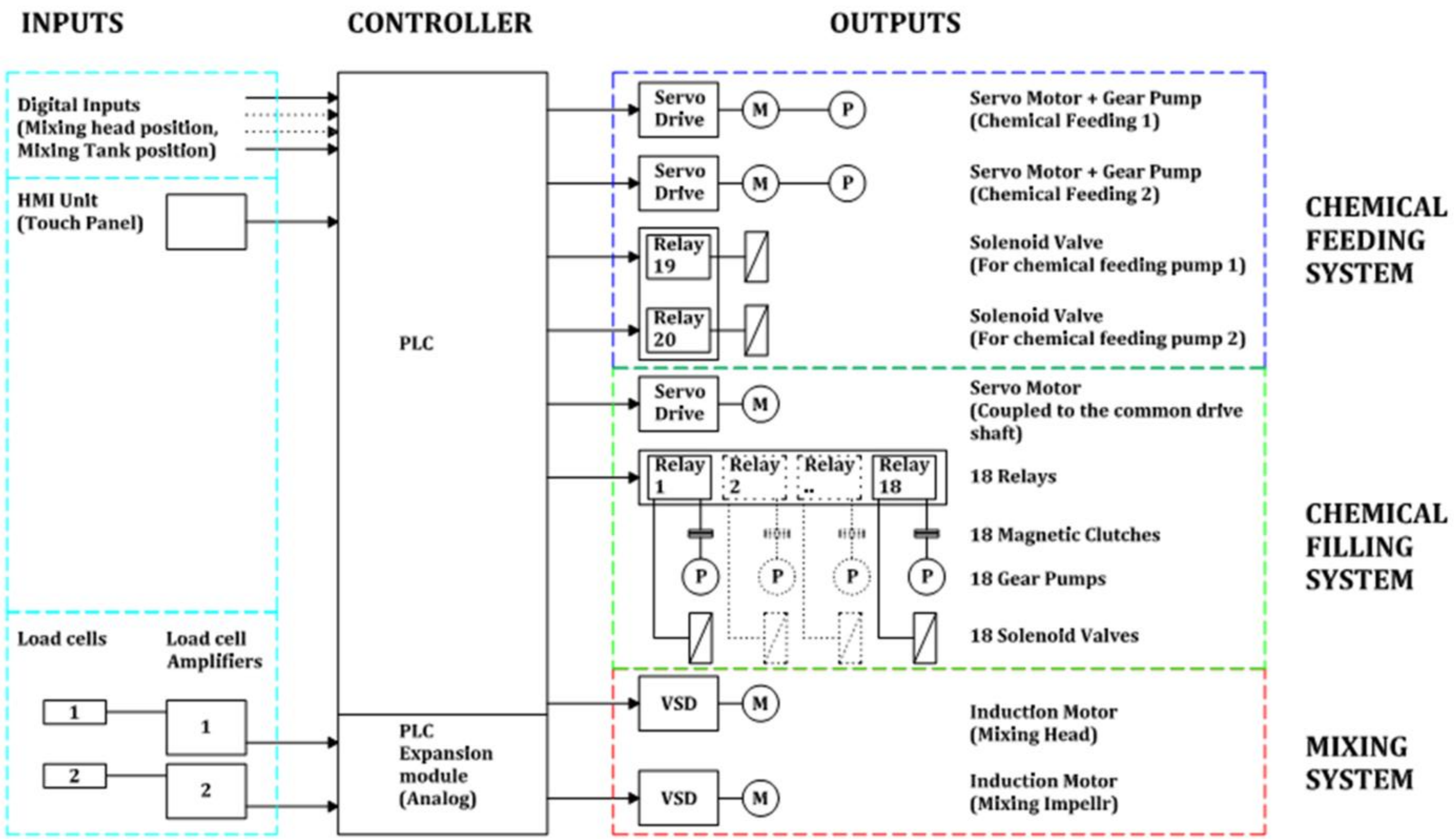


Fig 2.3 Control System Diagram

When the control system of the machine shown in Fig 2.3 is considered the brain of the system is the controller, here a PLC is used which can be reliably used in the industrial environment. In addition to the basic PLC unit an analog expansion module and a HMI unit also are attached. There are three types of inputs coming to the PLC. There are several digital inputs coming from mixing head position proximity sensors and tank position limit switch input and tank size identification photo eye sensor inputs. Machine start and stop signals, compound type and size selection inputs and data entering part is done via the HMI and it communicates with the PLC via their communication ports. The two analog signals coming from the two load cells are amplified through load cell amplifiers and inputs to the PLC analog module as a 0-10V voltage signal. The PLC outputs in this case are also in three types. There are eighteen numbers of relay outputs relevant to filling pump clutch and solenoid valve operations and two relay outputs relevant to two feeding pump solenoid valve operations. The mixing head up and down operations are also controlled by relay outputs. Two transistor outputs are used for filling servo pump drive operation and two feeding pump drives operation as a common output. Also for enabling the servo drives three relay outputs are used parallel to the pulse outputs. An analog voltage output is used for controlling the impeller speed via a VSD. Above are the main inputs and outputs necessary for the operation and other than them it is possible to use inputs or outputs as required.

2.2 Electrical and Control System

2.2.1 Selection of Controller

For selection of controller number of input and outputs and type of inputs and outputs are important. Also sensor inputs and relay outputs are all should be 24V DC.

Inputs			
Digital Inputs		Analog Inputs	
1	Mixing head up	1	Load cell 1 Voltage Input
2	Mixing head down1	2	Load cell 2 Voltage Input
3	Mixing head down2		
4	Mixing station interlock		
5	Tank 200		
6	Tank 500		
7	Tank 1000		
8	Mixing head up		

Table 2.1 Controller inputs

Outputs					
1	Pulse-Filling Pump Drive	**15**	Filling pump 2	**29**	Filling pump 16
2	Pulse-Feeding Pump Drive	**16**	Filling pump 3	**30**	Filling pump 17
3	Mixing Head Down	**17**	Filling pump 4	**31**	Filling pump 18
4	Mixing Head Up	**18**	Filling pump 5		
5	Impeller Rotate(Analog)	**19**	Filling pump 6		
6	Servo -1 On	**20**	Filling pump 7		
7	Alarm Reset -1	**21**	Filling pump 8		
8	Servo -2 On	**22**	Filling pump 9		
9	Alarm Reset -2	**23**	Filling pump 10		
10	Servo -3 On	**24**	Filling pump 11		
11	Alarm Reset -3	**25**	Filling pump 12		
12	Feed Pump 1 Auto	**26**	Filling pump 13		
13	Feed Pump 2 Auto	**27**	Filling pump 14		
14	Filling pump 1	**28**	Filling pump 15		

Table 2.2 Controller Outputs

According to Table-3 and Table-4 controller inputs and outputs can be summarized as follows.

No of Digital Inputs	- 8
No of Analog Inputs	- 2
No of Relay Outputs	- 28
No of Transistor Outputs	- 2
No of Analog Outputs	- 1

Controller power supply can be either 230V AC or 24V DC. Input and output handling voltage should be 24V DC. Also the controller should be easily replaceable, should be withstand in industrial environment. By considering above all factors below controller and expansion modules are selected.

XINJE PLC, XC3-60RT-E

Power Supply-220V AC

36 DC 24V Inputs

22 Relay Outputs

2 Transistor outputs

Fig 2.4XINJE PLC, XC3-60RT-E

XINJE PLC Expansion Unit, XC 16X16YR-E

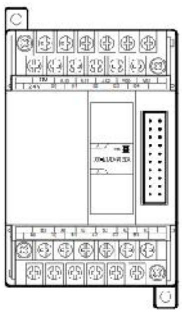
Power Supply-220V AC

16 DC 24V Inputs

16 Relay Outputs

Fig 2.5XINJE PLC Expansion Unit, XC 16X16YR-E

XINJE PLC Analog Expansion Unit, XC-E2AD2PT2DA



Items	Analog input（AD）		Temperature input（PT）	Analog voltage output（DA）	
Analog input	Current	0~20mA 4~20mA	PT100	-	
	Voltage	0~5V 0~10V			
Temperature range	-		-100~327℃	-	
Maximum input range	0~40mA		-	-	
Analog output range	-		-	Voltage	0～10V，0～5V
				Current	0～20mA、4～20mA

Fig 2.6XINJE PLC Analog Expansion Unit, XC-E2AD2PT2DA

2.2.2 Selection of Pumps

The below factors should be considered in selection of suitable pump.

- Maximum flow rate - 2.6 l/m (from the existing chemical feeding data in manual process)
- Withstand to Chemicals
- Maximum Viscosity – 25pois

Since different types of chemicals are used the pump should be highly chemical resistant and a gear pump is suitable for this application since high viscous chemicals are used. Also the maximum flow rate should be gained by the pump. Therefore it is decided to select ROTOFLUID gear pump for the application and from the pump specification chart in Table 2.3 the pump is selected.

MODEL - SIZE - CAPACITY & POWER CHART

PUMP MODEL FTSS	SUCTION & DELIVERY	CAPACITY at 1440 RPM			POWER REQ. NO LOAD VISCOUS H.P.at			Unit H.P Per Kg. press	PUMP DIMENSION OVER ALL					PUMP DIMENSION MOUNTING & SHAFT									WT. OF PUMP IN KG.
		LPM	US GPM	M3/hr	200 CST	500 CST	750 CST		A	F G	H2	L1	L2	E	E1	E2	H	H1	D D1	C C1	P Q	B1	
015	1/8"X1/8"	5.0	1.3	0.3	0.14	0.18	0.30	0.015	123	54	101	91	32	40	120	90	63	50.5	11.5	17	4	25	1.80
025	1/4"X1/4"	8.3	2.2	0.5	0.20	0.25	0.35	0.02	129	12.5	101	94	35	40	120	90	63	50.5	8	3	13	25	2.00
040	3/8"X3/8"	16.6	4.4	1.0	0.35	0.40	0.55	0.04	134	61	112	98	36	50	120	88	71	57	11.5	17	4	25	3.00
050	1/2"X1/2"	25	6.6	1.5	0.40	0.50	0.70	0.06	146	14	112	103	41	50	120	88	71	57	8	3	13	25	3.50
075	3/4"X3/4"	33.3	8.8	2.0	0.45	0.55	0.90	0.09	160	72.5	128	123	46	55	140	92	90	73	14	25	5	35	4.50
100	1"X1"	50	13.2	3.0	0.50	0.60	1.0	0.13	177	17	128	115	52	55	140	92	90	73	10.5	3	16	35	5.00
125	1 ¼"X1 ¼"	100	26.4	6.0	0.65	0.85	1.25	0.28	210	90	149	143	66	50	155	111	100	79	18	30	6	38	7.00
150	1 ½"X1 ½"	125	33.0	7.5	0.75	0.95	1.50	0.35	225	21	149	151	73	50	155	111	100	79	12	3	20.5	38	10.50
200	2" X 2"	150	39.6	9.0	0.90	1.15	1.75	0.45	251	103	167	162	85	70	190	131	112	87	24	30	8	40	20.50
200		200	52.8	12.0	1.00	1.25	2.15	0.60	281	25	167	179	97	70	190	131	112	87	14	5	27	40	24.00
250	2 ½"X2 ½"	250	66.0	15.0	1.20	1.40	2.35	0.65	299	122	197	206	93	85	200	161	132	102	28	40	8	50	35.00
250		300	79.25	18.0	1.40	1.65	2.50	0.77	319	30	197	218	101	85	200	161	132	102	16	5	32	50	40.00

SPECIAL NOTES

For calculating the power requirement at duty point, multiply the duty point pressure with unit horse power & add no load viscous power c appropriate viscosity, provide safety margin before fixing the rating of the prime mover. For higher viscosity further margin may be kept or th manufacturer may be consulted. All sizes of **"FTSS"** pumps are designed to run at 1440 RPM up to viscosity of 500 CST. For small size pump u to 1" same can be safely run at 1440 RPM even at higher viscosity up to 1000 CST with additional horse power. For sizes above 1" reduc the speed to 960 RPM for viscosity up to 1000 CST. For higher viscous liquids, consult the manufacturer to avoid cavitation & over loadin problem.

Table 2.3 ROTOFLUID gear pump specification chart.

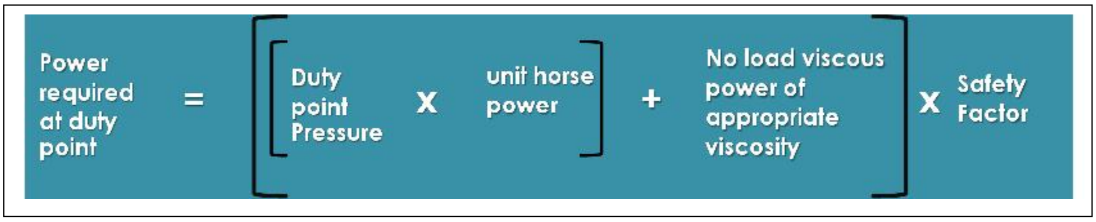
ROTOFLUID rotary gear pumps are designed to operate at 1440 rpm.For high viscous fluids rpm should be reduced. Therefore assuming the pump operates at 500 rpm to deliver 2.6 l/m and since speed-flow characteristics is linear for gear pumps

Required pump flow at 1440rpm = 2.6 l/m X (1440/500) = 7.5 l/m

Accordingly the above marked pump in Table 2.3 is selected.

2.2.3 Selection of Drive Motors

From Table 2.3



Finding the duty point pressure

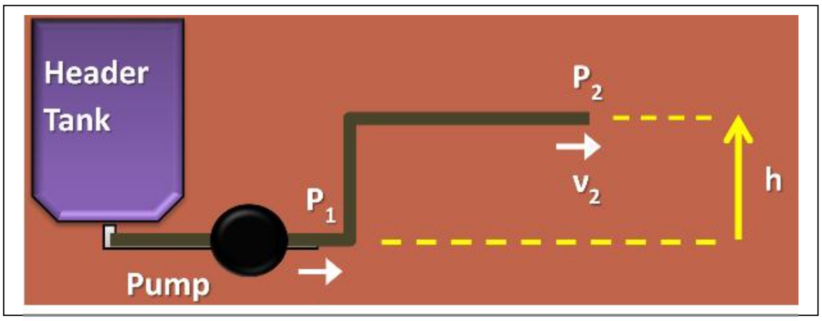


Fig 2.7 Fluid head at pump

Assume the flow is laminar

Density of fluid-ρ

For external gear pumps flow rate is constant, for fluids above 100cp viscosity

Hence, $V_1 = V_2$

Differential Pressure	$= P_2 - P_1$
	$= (h \rho g + \frac{1}{2} \rho V_1^2)-(0+ \frac{1}{2} \rho V_2^2)$
	$= h \rho g$

Let, $h = 0.6m$ (max)

$\rho = 1800\ kg/m^3$ (max density of fluids), g	$= 9.8\ ms^{-2}$
Differential Pressure	$= P_2 - P_1$
	$= (h \rho g + \frac{1}{2} \rho V_1^2)-(0+ \frac{1}{2} \rho V_2^2)$
	$= h \rho g$
	$= 0.5x1800x9.8 = 8820$ Pa
	$= 0.08\ kg/cm^2$

From Table 2.3

Unit horse power	= 0.02
No load viscous power at 750cst	=0.35
Power required = 0.08 x 0.02 + 0.35 x S.F	= 0.352hp x S.F

Take,

S.F for Filling pumps drive shaft motor	= 3

S.F for Feeding pump drive motor = 1.5

Therefore,

Power required for Filling pumps drive shaft = 0.352x3 =1.056hp= 0.75kW

Power required for Feeding pump = 0.352x1.5 = 0.48hp= 0.36kW

Therefore from ASDA servo motor specification table suitable motors and drives are selected.

Motion ASDA-B2
AC Servo Motors and Drives
ECMA Specifications
Low Inertia Series

Model: ECMA Series	C204	C206		C208		C209		C210	
	01	02	04	04	07	07	10	10	20
Rated output power (kW)	0.1	0.2	0.4	0.4	0.75	0.75	1.0	1.0	2.0
Rated torque (N-m)[*1]	0.32	0.64	1.27	1.27	2.39	2.39	3.18	3.18	6.37
Maximum torque (N-m)	0.96	1.92	3.82	3.82	7.16	7.14	8.78	9.54	19.1
Rated speed (r/min)			3000			3000		3000	
Maximum speed (r/min)			5000			3000		5000	
Rated current (A)	0.90	1.55	2.60	2.60	5.10	3.66	4.25	7.30	12.05
Maximum current (A)	2.70	4.65	7.80	7.24	15.3	11	12.37	21.9	36.15
Power rating (kW/s)	27.7	22.4	57.6	22.1	48.4	29.6	38.6	38.1	90.6
Rotor moment of inertia ($\times 10^{-4} kg.m^2$)(Without brake)	0.037	0.177	0.277	0.68	1.13	1.93	2.62	2.65	4.45
Mechanical time constant (ms)	0.75	0.80	0.53	0.73	0.62	1.72	1.20	0.74	0.61
Torque constant-KT (N-m/A)	0.36	0.41	0.49	0.49	0.47	0.65	0.75	0.44	0.53
Voltage constant-KE (mV/(r/min))	13.6	16.0	17.4	18.5	17.2	27.5	24.2	16.8	19.2

Table 2.4 ASDA AC Servo motor specifications.

	Motor	Motor Drive
Chemical Filling Pumps	DELTA AC Servo Motor Model-ECMA-C20807ES Input-110V 5.1A Output 3000r/min 2.39N.m 0.75kW	Delta AC Servo Drive Model-ASD-B2-0721-B Power-750W Input-200-230V 3PH 50/60Hz 3.65A 200-230V 1PH 50/60Hz 6.78A Output-110V 0-250Hz 5.1A
Chemical Feeding Pumps	DELTA AC Servo Motor Model-ECMA-C20604ES Input-110V 2.6A Output 3000r/min 1.27N.m 0.4kW	Delta AC Servo Drive Model-ASD-B2-0421-B Power-400W Input-200-230V 3PH 50/60Hz 1.65A 200-230V 1PH 50/60Hz 3.27A Output-110V 0-250Hz 2.6A

Table 2.5 Selected Motors and Motor Drives.

2.2.4. Selection of Other Components

Finding Drive Pulley ratio between motors & pumps,

Pulleys should be selected for both chemical filling and chemical feeding pump drive systems.

Rated pump speed = 1440 rpm

Rated motor speed = 3000 rpm

Power = Torque x Angular speed

Hence, To achieve maximum power

Pulley ratio = 3000/1440 ≈ 2

For slip less operation timing belts and pulleys are used.

For maximum motor power (i.e. 0.75kW) timing belt can be selected.

Synchroflex ®			PIES
Belt	**Power Range**	**R.P.M**	**Speed**
M/T2/T2.5	0-0.5 kW	0-40,000 rpm	0-80 m/s
T5	0-5 kW	0-40,000 rpm	0-80 m/s
T10	0-30 kW	0-15,000 rpm	0-60 m/s
T20	0-100 kW	0-6,000 rpm	0-40 m/s
AT3	0-5 kW	0-40,000 rpm	0-80 m/s
AT5	0-15 kW	0-40,000 rpm	0-80 m/s
AT10	0-70 kW	0-15,000 rpm	0-60 m/s
AT20	0-250 kW	0-6,000 rpm	0-40 m/s

Table 2.6 Synchroflex Timing belt specifications.

Therefore from the table selected Timing belt type is**T5**

For filling Pump drive system to achieve overall pulley ratio of 2, between motor and pump pulleys are selected as below.

T5 Pulley to suit 16mm wide Belt

Pulley No.	Type	teeth	Pcd	Od	Dm	Df	F	L	d	Weight
AL27T 5/10-2	6F	10	15.92	15.05	8	19.5	21	27	-	0.016
AL27T 5/12-2	6F	12	19.10	18.25	11	23.0	21	27	-	0.022
AL27T 5/14-2	6F	14	22.29	21.45	14	25.0	21	27	-	0.026
AL27T 5/15-2	6F	15	23.88	23.05	16	28.0	21	27	6	0.029
AL27T 5/16-2	6F	16	25.47	24.60	18	32.0	21	27	6	0.035
AL27T 5/18-2	6F	18	28.65	27.80	20	32.0	21	27	6	0.043
AL27T 5/19-2	6F	19	30.25	29.40	22	36.0	21	27	6	0.049
AL27T 5/20-2	6F	20	31.83	31.00	23	36.0	21	27	6	0.053
AL27T 5/22-2	6F	22	35.02	34.25	24	38.0	21	27	6	0.054
AL27T 5/24-2	6F	24	38.21	37.40	26	42.0	21	27	6	0.076
AL27T 5/25-2	6F	25	39.80	39.00	26	44.0	21	27	6	0.081
AL27T 5/26-2	6F	26	41.39	40.60	26	44.0	21	27	6	0.085
AL27T 5/27-2	6F	27	42.98	42.20	30	48.0	21	27	8	0.090
AL27T 5/28-2	6F	28	44.58	43.75	32	48.0	21	27	8	0.092
AL27T 5/30-2	6F	30	47.76	46.95	34	51.0	21	27	8	0.105
AL27T 5/32-2	6F	32	50.94	50.10	38	54.0	21	27	8	0.123
AL27T 5/36-2	6F	36	57.31	56.45	38	63.0	21	27	8	0.160
AL27T 5/40-2	6F	40	63.66	62.85	40	66.0	21	27	8	0.193
AL27T 5/48-0	6	48	76.42	75.55	50	_	21	27	8	0.280
AL27T 5/60-0	6	60	95.52	94.65	65	_	21	27	8	0.430

Table 2.7 Selected timing pulleys for filling pumps.

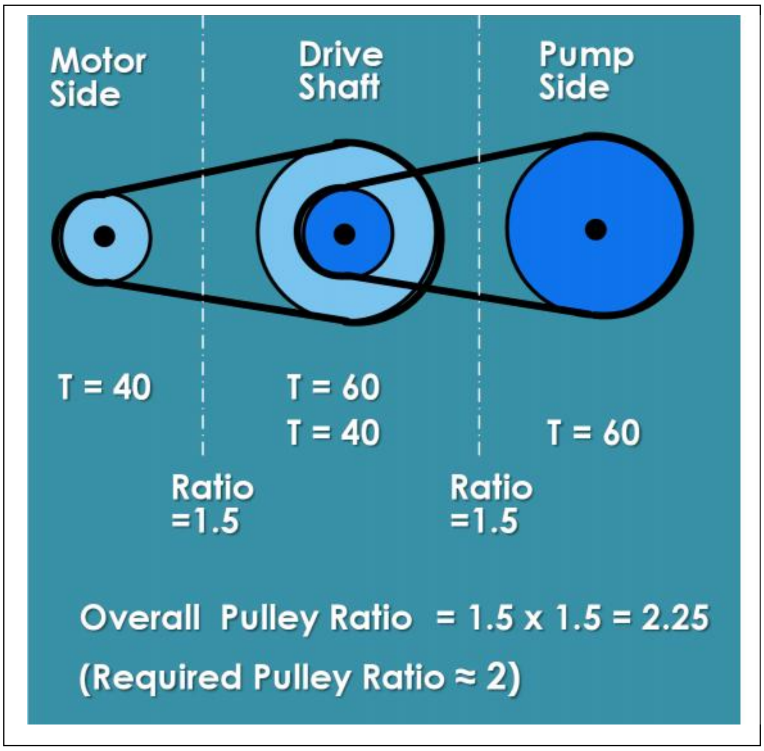


Fig 2.8 Pulley arrangement of filling pump operation

For feeding pump drive system to achieve overall pulley ratio of 2, between motor and pump pulleys are selected as below.

T5 Pulley to suit 16mm wide Belt

Pulley No.	Type	teeth	Pcd	Od	Dm	Df	F	L	d	Weight
AL27T 5/10-2	6F	10	15.92	15.05	8	19.5	21	27	-	0.016
AL27T 5/12-2	6F	12	19.10	18.25	11	23.0	21	27	-	0.022
AL27T 5/14-2	6F	14	22.29	21.45	14	25.0	21	27	-	0.026
AL27T 5/15-2	6F	15	23.88	23.05	16	28.0	21	27	6	0.029
AL27T 5/16-2	6F	16	25.47	24.60	18	32.0	21	27	6	0.035
AL27T 5/18-2	6F	18	28.65	27.80	20	32.0	21	27	6	0.043
AL27T 5/19-2	6F	19	30.25	29.40	22	36.0	21	27	6	0.049
AL27T 5/20-2	6F	20	31.83	31.00	23	36.0	21	27	6	0.053
AL27T 5/22-2	6F	22	35.02	34.25	24	38.0	21	27	6	0.054
AL27T 5/24-2	6F	24	38.21	37.40	26	42.0	21	27	6	0.076
AL27T 5/25-2	6F	25	39.80	39.00	26	44.0	21	27	6	0.081
AL27T 5/26-2	6F	26	41.39	40.60	26	44.0	21	27	6	0.085
AL27T 5/27-2	6F	27	42.98	42.20	30	48.0	21	27	8	0.090
AL27T 5/28-2	6F	28	44.58	43.75	32	48.0	21	27	8	0.092
AL27T 5/30-2	6F	30	47.76	46.95	34	51.0	21	27	8	0.105
AL27T 5/32-2	6F	32	50.94	50.10	38	54.0	21	27	8	0.123
AL27T 5/36-2	6F	36	57.31	56.45	38	63.0	21	27	8	0.160
AL27T 5/40-2	6F	40	63.66	62.85	40	66.0	21	27	8	0.193
AL27T 5/48-0	6	48	76.42	75.55	50	–	21	27	8	0.280
AL27T 5/60-0	6	60	95.52	94.65	65	–	21	27	8	0.430

Table 2.8 Selected timing pulleys for feeding pumps.

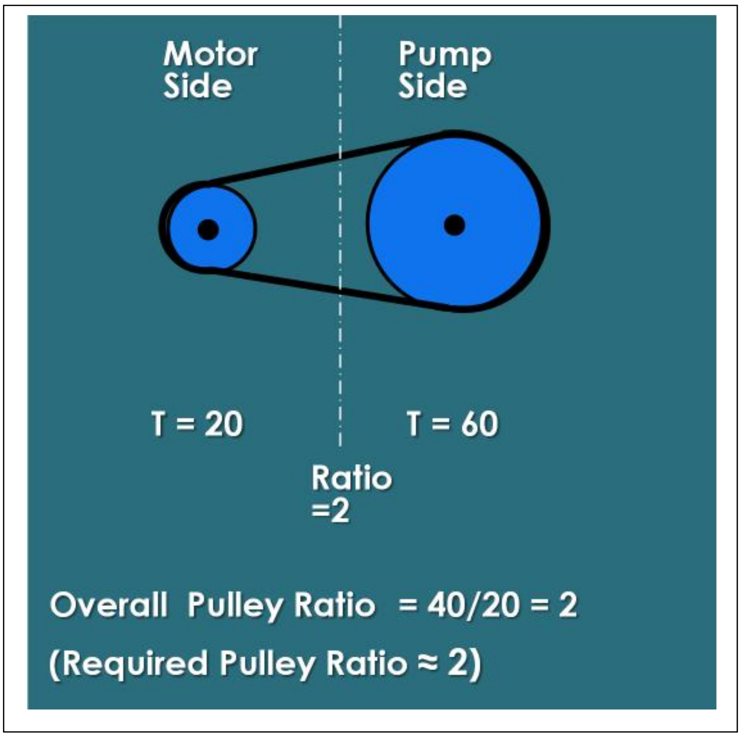


Fig 2.9Pulley arrangement of feeding pump operation

Selecting Electro Magnetic Clutch for Filling Pump

Assuming motor power is transmitted the pump without loss,

Considering maximum pump speed of 1440 rpm

Torque exerted at clutch can be taken as below

Power = Torque x Angular speed

Torque = (0.75x1000)/ (1440x2π/60) = 5 Nm

Considering the torque, required clutch can be selected.

型號 MODEL		TJ-A1-0.6	TJ-A1-1.5	TJ-A1-2.5	TJ-A1-5	TJ-A1-10	TJ-A1-20	TJ-A
Static Friction Torque		0.55(5.5)	1.1(11)	2.2(22)	4.5(45)	9(90)	17.5(175)	35(
Dynamic Friction Torque		0.5(5.0)	1.0(10)	2.0(20)	4(40)	8(80)	16(160)	32(
Power (24V)(W) at 20C		11	15	20	25	35	45	6
Radius	A	63	80	100	125	160	200	2
	B	67.5	85	106	133	169	212.5	2
	C1	80	100	125	150	190	230	2
	C2	72	90	112	137	175	215	2
	C3	35	42	52	62	80	100	1
	D1	12 15	15 20	20 25	25 30	30 40	40 50	50
	D2	12 15	15 20	20 25	25 30	30 40	40 50	50
	E	27.5	31	41	49	65	83	1
	F	23	28	40	45	62	77	1
	Y	5	6	7	7	9.5	9.5	1
Shaft	H	24	26.5	30	33.5	37.5	44	5
	J	3.5	4.3	5	5.5	6	7	
	K	2	2.5	3	3.5	4	5	
	L1	43.05	51.3	60.9	70.8	85	101.2	11
	L2	31.55	35.3	40.9	46.8	54	65.2	75
	M1	22	24.1	27	30	34	40.15	47
	M2	15	20	25	30	38	45	5
	P	7.5	9.5	8.9	9.5	9.5	10.5	1
	T	6	8	10	12	14	18	2
	m	2-M4	2-M5		2-M6	2-M8		2-
	a		0.2(±0.05)		0.3(+0.05/-0.1)		0.5(-0/-0.2)	
	b	4 5	5 5	5 7	7 7	7 10	10 12	12

bore diameter

Table 2.9 Tianji Electromagnetic clutch specifications.

According to the table **TJ-A1-1.5** clutch is selected.

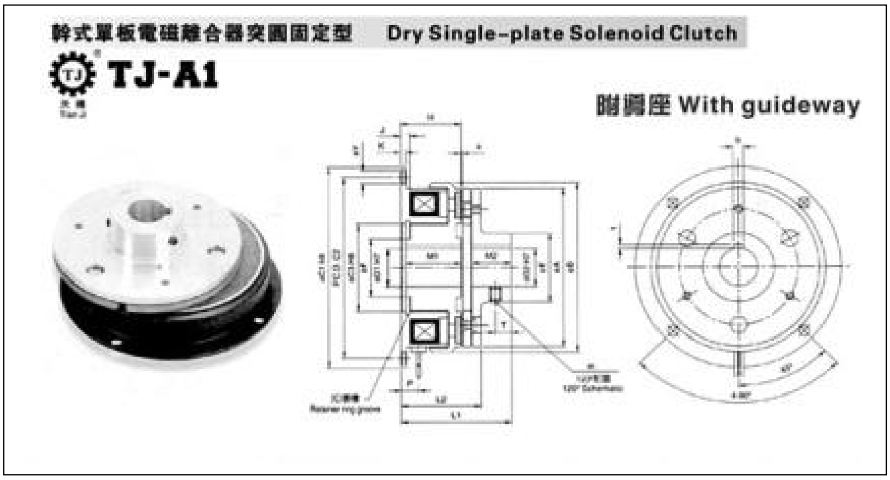


Fig2.10 Tianji TJ-A1 Clutch

2.2.5. Selection of load cell

There are different types of load cells used in industries depending on the application.

1) Beam load cells(Tension, Compression)
2) Column load cells (Compression)
3) "S" load cells (Tension, Compression)
4) Diaphragm load cells (Compression)

When selecting a load cell for a specific application the mechanical structure is a important factor. In case of the automated compounding machine the intermediate collecting tank structure is concerned.

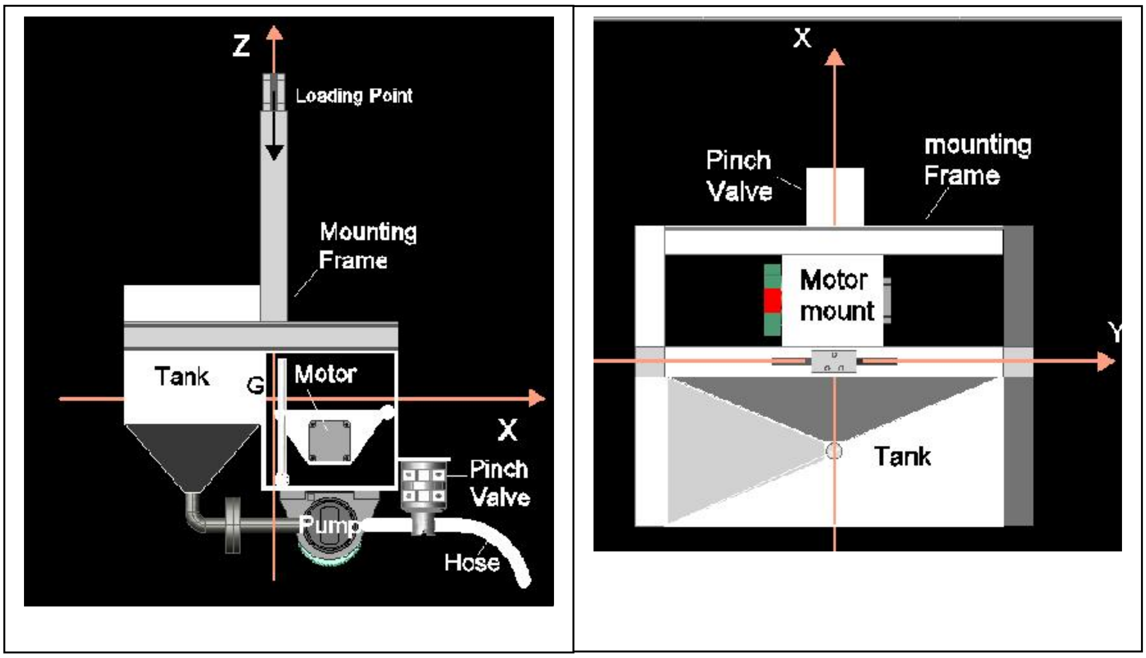


Fig 2.11 Intermediate Collecting tank and structure

Since the structure is not symmetrical around y axis as illustrated in Fig- application of multiple point load cells is not effective for this system. Also it is easy to hang this system rather than mounting on a platform. Therefore this will be a tension application and hence single point type load cell needs to be selected. Using of both single point beam load cell and "S" load cell are possible. Considering the necessity of rigid mounting of the system single point beam type load cell is selected for this application.

Determination of the Capacity of the Load Cell

Maximum chemical weight to be measured (Load) = 20kg

Weight of the intermediate tank structure (initial weight) = 39kg

$$\textbf{\textit{The Capacity of the Load Cell}} \geq [(\textbf{\textit{Impact Coefficient}} \times \textbf{\textit{Load}} + \textbf{\textit{Initial Load}}) \times \textbf{\textit{Load ecentricity coefficient}} \times \textbf{\textit{Load Imbalance coefficient}}]/(\textbf{\textit{Number of Load Cells}})$$

Impact Coefficient = 1.2

Load eccentricity coefficient = 1.2

Load Impact Coefficient = 1 (for single load cell)

$$\textbf{\textit{The Capacity of the Load Cell}} \geq \frac{[(\mathbf{1.2} \times \mathbf{20} + \mathbf{39}) \times \mathbf{1.2} \times \mathbf{1}]}{\mathbf{1}}$$

$$\geq \mathbf{75.6kg}$$

Therefore selected load cell is A&D,LCB04 ,100kgf

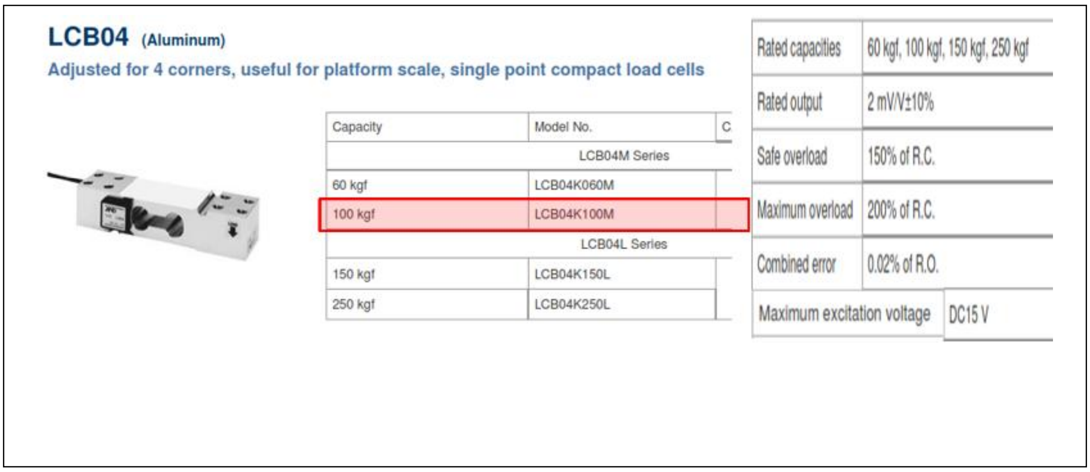


Fig 2.12 LCB04 Load cell specifications

2.2.6. Interfacing of load cell

The strain gauge type load beam cell structure is shown in Fig 2.13

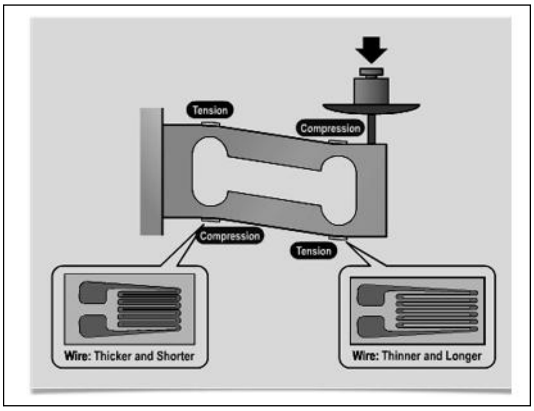


Fig 2.13 Strain gauge type beam load cell structure

The force exerted at the loading point is sensed by strain gauges attached. According to the Fig- it can be seen that two strain gauges are subjected to compression and the other two are subjected to tension. These four strain gauges are arranged in a Wheatstone bridge circuit. A Wheatstone bridge is a circuit of four resistors with a known voltage applied as in Fig 2.14.

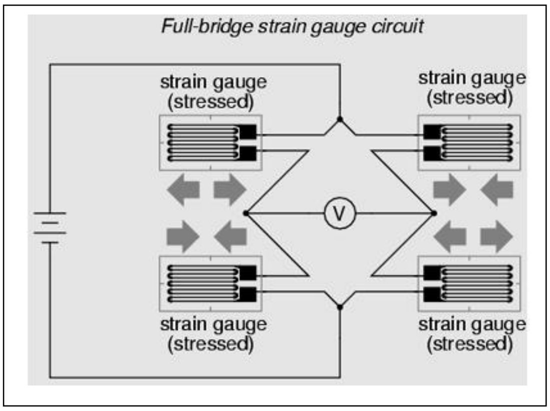


Fig 2.14 Four strain gauges arranged in a Wheatstone bridge

When the load cell is loaded the resistance of the strain gauges is changed due to the elongation. Accordingly the output voltage is also changed. The input voltage to the load cell is called excitation voltage and typically it is between 5-10Volts DC. The output voltage of the load cell is a millivolt (mV) signal (maximum of 30mV).

Normally the rated output of a load cell is given by millivolt per volt (mV/V) and that of the selected load cell is 2mV/V.

If the maximum excitation voltage is supplied to the load cell (15V) the output for the full load (i.e. 100kg) is 30mV.

The PLC analog module input voltage is 0-10V. Therefore for the better performance (i.e. for high resolution) the output load cell voltage should be amplified and input to the PLC. Therefore a load cell amplifier should be used.

Selection of load cell amplifier

In case of selecting a suitable load cell amplifier for the system below points needs to be considered.

- Transducer supply (Excitation voltage to the load cell) should be less than 15V
- It should be able to measure maximum of 30mV input voltage from the load cell
- Voltage output should be within the range of 0-10V (input to the PLC)
- There should be a digital input for external taring (24V DC out from PLC)
- Should be able to calibrate for initial and maximum loads.

The load cell amplifier in Fig- is full fill the above points and also it has a programmable facility. Therefore this amplifier is suitable for the application.

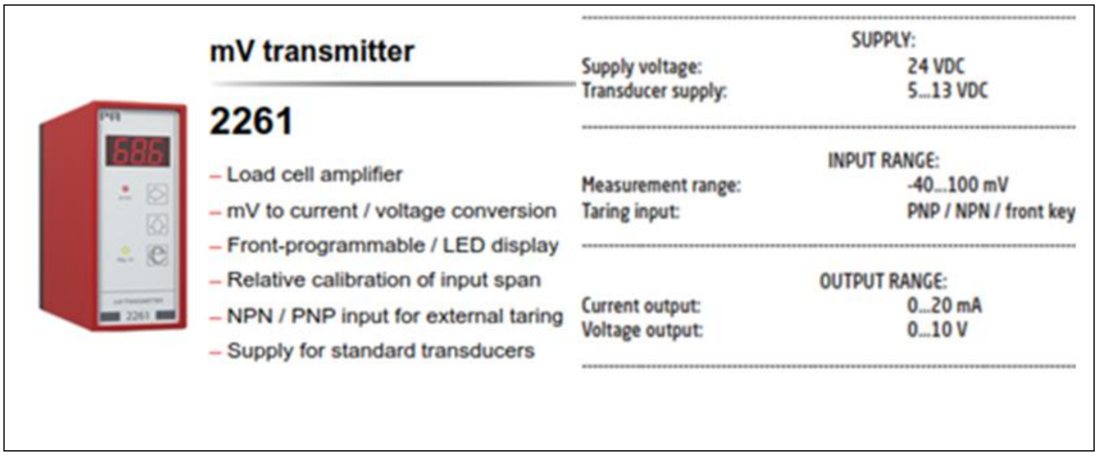


Fig 2.15 Selected Load cell Amplifier

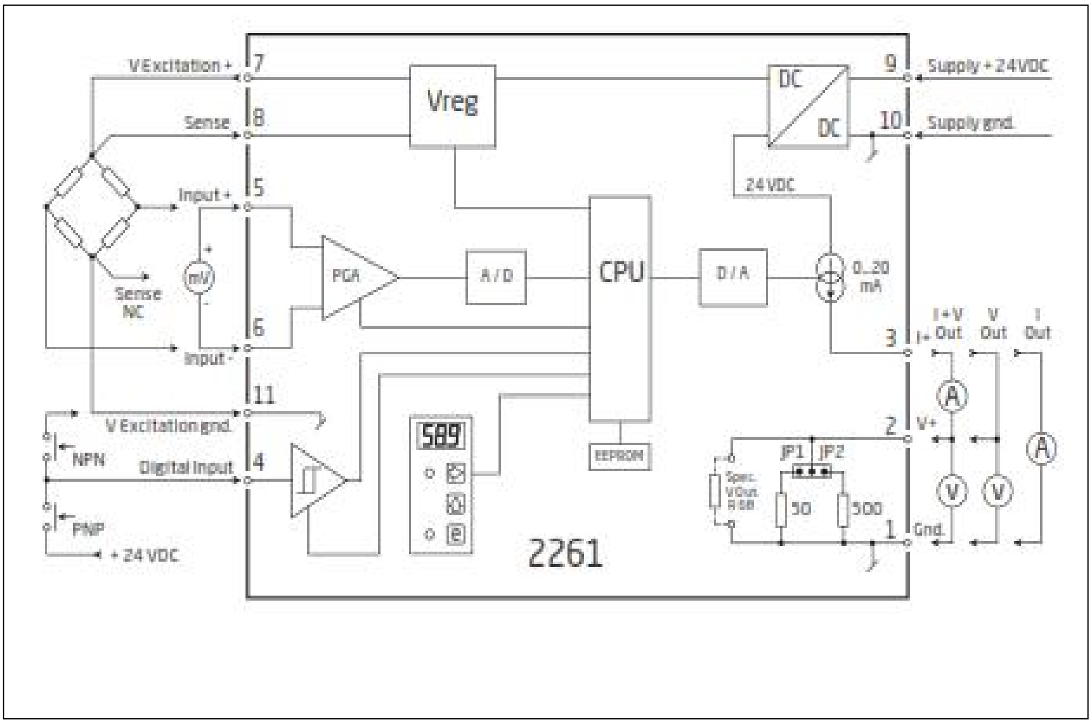


Fig 2.16 Load cell connection and output signals of the amplifier

According to the Fig-2.16 the load cell excitation voltage pins are pin 7(+) and pin 11(ground). The load cell output signal can be connected to pin 5(+) and pin 6(-). Pin 9 and 10 are the 24V DC supply voltage pins. The output of the amplifier can be programmable either as a voltage or current output. In this case it is programmed as a voltage out and by short circuiting pin 2 and 3 the voltage signal is available between pin 2 and 1. The external taring input also can be programmed either as a negative or positive input. In this case it is programmed as positive voltage input which is the relay output signal from the PLC (+24V DC). The amplifier can be calibrated according to the instructions given in the manual by using a standard known weight.

2.3. Mechanical System Design

2.3.1. Pumps Drive Shaft Design

All the pumps are driven by a common shaft which comprises of several shafts each coupled to the other by means of jaw couplings. Left side of the common shaft is shown in Fig-24. Drive motor is coupled with the shaft at the mid portion of the whole shaft as shown in Fig-25. Forces are acting on the shaft at each timing wheel attached to the shaft.

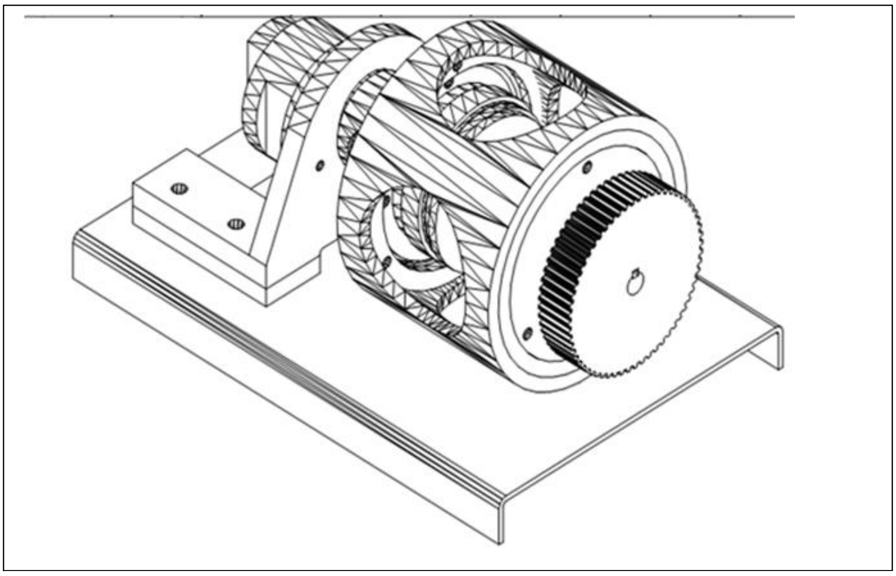


Fig2.17 Pump and Clutch Assembly

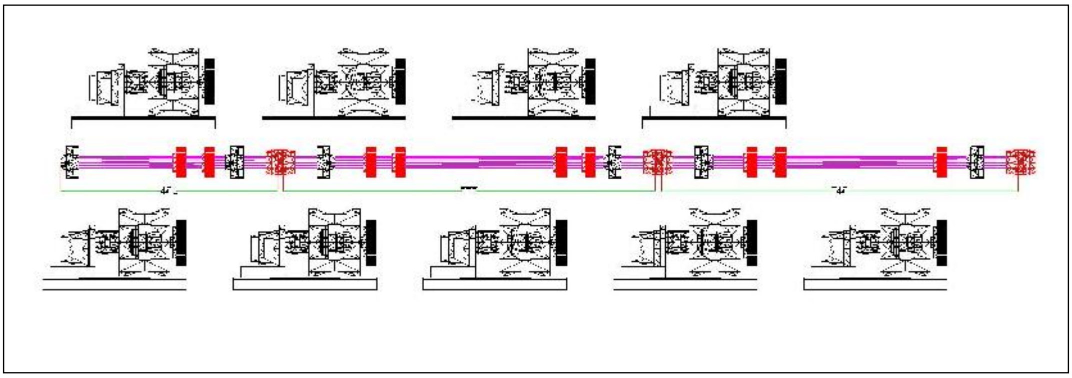


Fig 2.18 Pumps and drive shaft arrangement

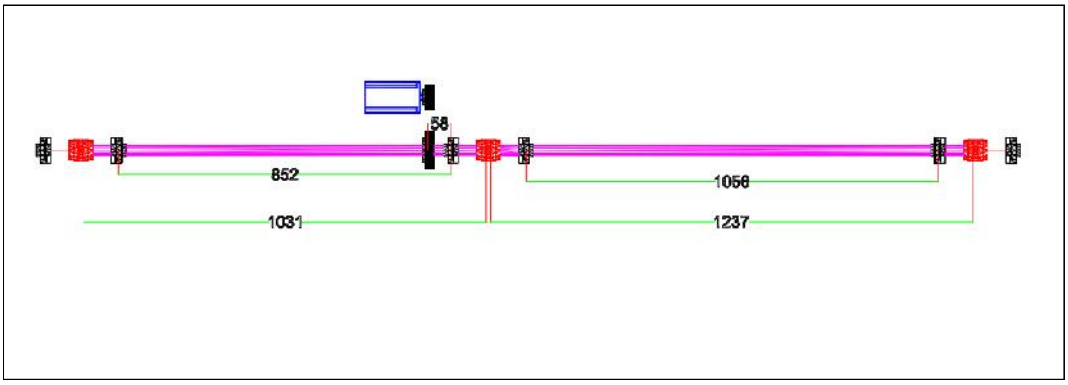


Fig 2.19 Motor and drive shaft arrangement

Forces at each timing wheel should be found.

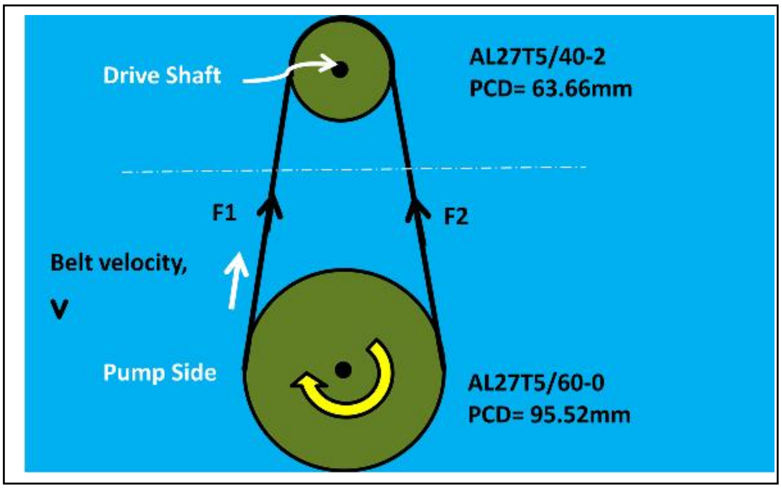


Fig 2.20 Forces on Timing belt at drive shaft pump pulley

For the pulley arrangement,

Power Transmitted = (F1-F2).v, where, v = r.ω

v = (0.09552/2) .(1440x2π/60)

= 7.2 m/s

Assuming total motor power is transmitted to pump without loss

0.75x1000 = (F1-F2)7.2

(F1-F2) = 104.2 N

According to Figure 24&25 below shaft lengths should be considered

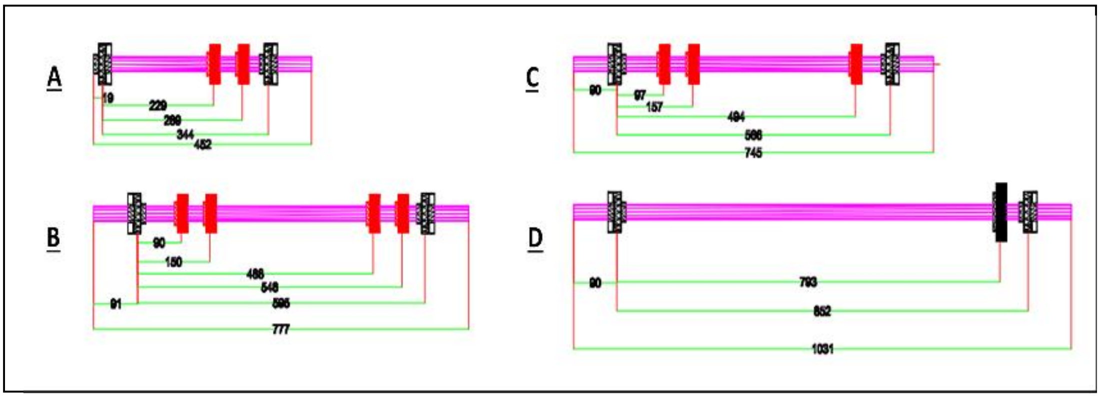


Fig 2.21 Portions of Drive shaft

Considering Shear & Bending moments of shaft "A"

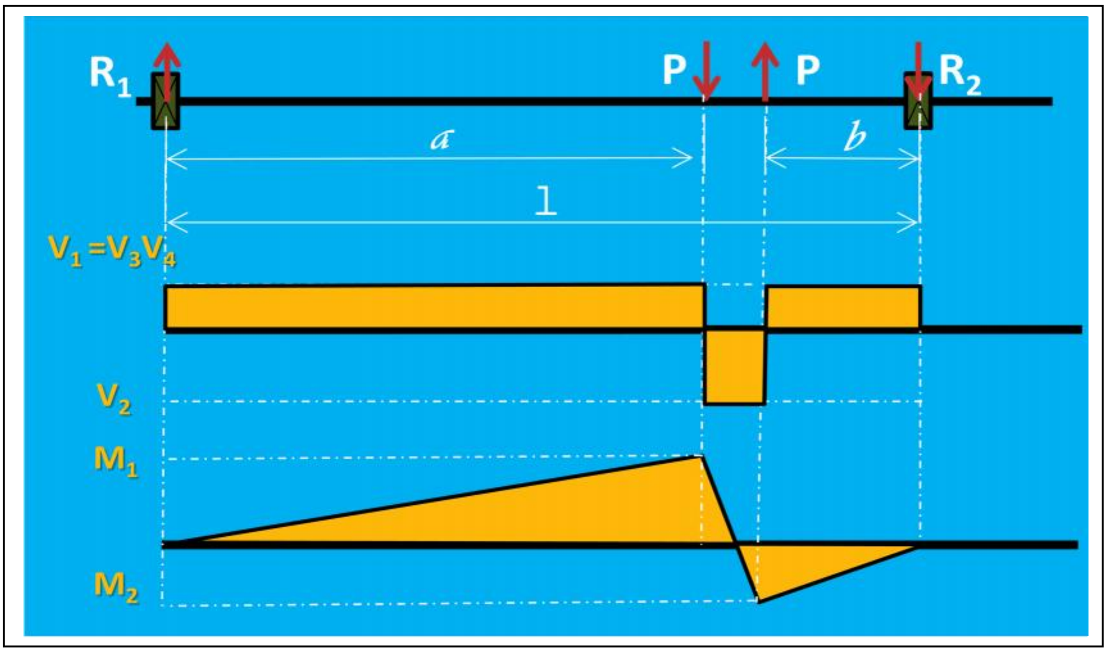


Fig 2.22 Shear Force and Bending Moment Diagrams Of Shaft "A"

$V_1 = R_1 = P(l\text{-}a\text{-}b)/l$ $= 18.5$ N

$V_2 = R_1 - P = -85.7$, V_3 $= 18.5$N

$V_4 = R_2 = P(l\text{-}a\text{-}b)/l$ $= 18.5$ N

$M_1 = R_1\, a$ $= 4.2$Nm

$M_2 = - R_2\, b$ $= -1$ Nm

Where,

l = 344 mm

a = 229 mm

b = 54 mm

P = 104.2 N

Considering Shear & Bending moments of shaft “B”

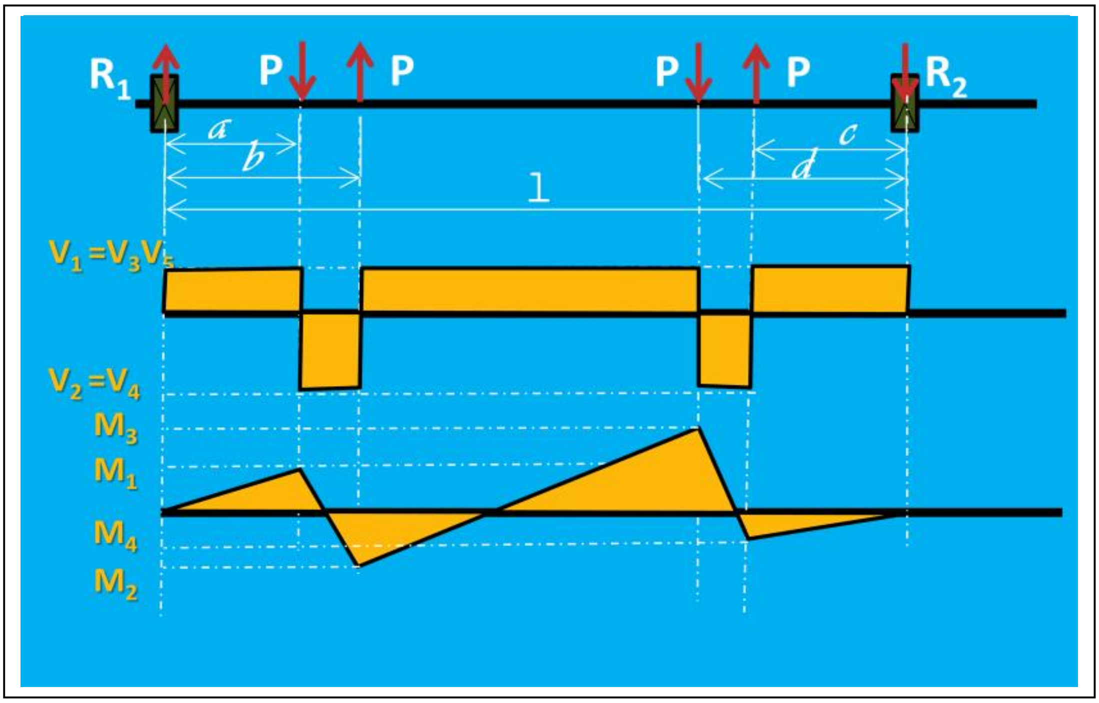


Fig 2.23 Shear Force and Bending Moment Diagrams of Shaft “B”

$V_1 = R_1 = P(b+d-a-c)/l \quad = 21\ N$

$V_2 = R_1 - P = -83N\ ,\ V_3 \quad = 21N$

$V_4 = -83N,\ V_5 = 21N$

$V_2 = R_2 = P(b+d-a-c)/l \quad = 21\ N$

$M_1 = R_1\, a \quad = 1.9\ Nm$

$M_2 = R_1\, b - P(b - a) \quad = -3.1\ Nm$

$M_3 = R_2\, d - P(d - c) \quad = 4\ Nm$

$M_4 = R_2\, c \quad = -1\ Nm$

Where, l = 595 mm, a = 90 mm

b = 150 mm, c = 48 mm

d = 108 mm, P = 104.2 N

Considering Shear & Bending moments of shaft “C”

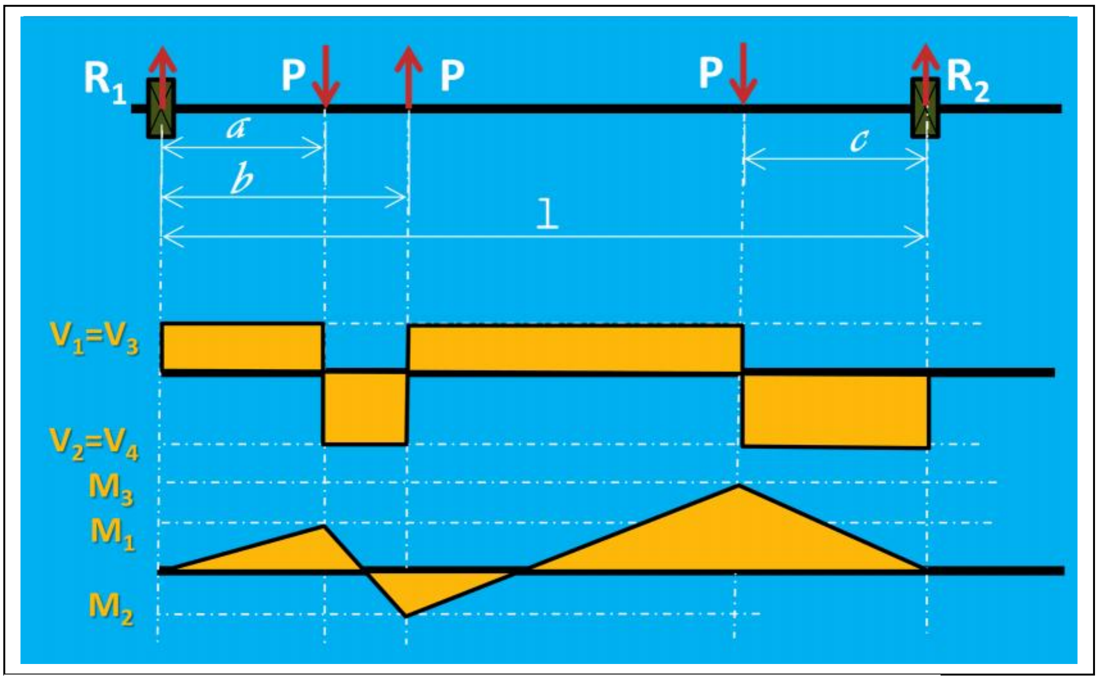


Fig 2.24 Shear Force and Bending Moment Diagrams of Shaft “C”

$V_1 = R_1 = P(b-a+c)/l$ $= 24.1$ N

$V_2 = R_1 - P$ $= -80.1$ N,

$V_3 = R_1 - P + P$ $= 24.1$ N,

$V_4 = R_1 - P + P - P$ $= -80.1$ N,

$V_5 = R_2 = P(l+a-b-c)/l$ $= 80.1$ N

$M_1 = R_1\, a$ $= 2.3$Nm,

$M_2 = R_1\, b - p(b - a)$ $= -2.5$Nm

$M_3 = R_2\, c$ $= 5.7$ Nm

Where, $l = 566$ mm, $a = 97$ mm

$b = 157$ mm, $c = 72$ mm

$P = 104.2$ N

Considering Shear & Bending moments of shaft "D"

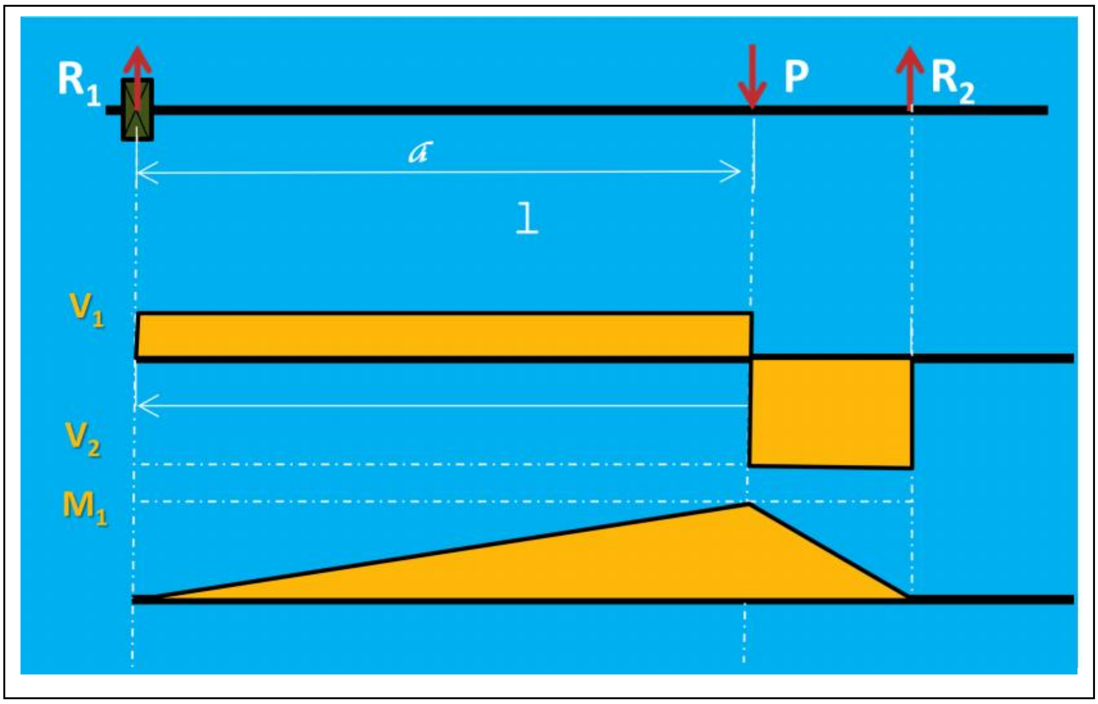


Fig 2.25 Shear Force and Bending Moment Diagrams of Shaft "D"

$V_1 = R_1 = P(l\text{-}a)/l$ $= 7.2$ N

$V_2 = -R_1 + P$ $= 97$ N

$M_1 = R_1 a$ $= 5.7$ Nm

Where, $l = 852$ mm $a = 793$ mm

$P = 104.2$ N

According to Shear force and bending moment calculations

Maximum Bending moment, M_b = 5.7 Nm

From motor specifications, and considering the pulley ratio

Maximum torque at shaft, M_t = max motor torque*pulley ratio

(Torsional Moment) M_t = 7.16*1.5

M_t = 10.74 Nm

According to the ASME CODE FOR SHAFT DESIGN for a shaft subjected to combined bending and torsional moments

Maximum Principle Stress, σ_1

$$\boldsymbol{\sigma}_1 = (16/\pi d^3)\,\{k_b M_b + \sqrt{[(k_b M_b)^2 + (k_t M_t)^2]}\}$$

Maximum Shear Stress, τ_{max}

$\tau_{max} = (16/\pi d^3)\,\sqrt{[(k_b M_b)^2 + (k_t M_t)^2]}$

The permissible value of Maximum Principle Stress, $\boldsymbol{\sigma}_1$

$$\boldsymbol{\sigma}_1 = S_{yt}/(f_s)$$

The permissible Maximum Shear Stress, τ_{max}

$T_{max} = 0.23\ S_{yt}$, (for shafts with keyways)

Where,

M_b = Maximum bending moment

M_t = Maximum torsional moment

d = diameter of the shaft

k_b = combined shock and fatigue factor applied to bending moment

k_t = combined shock and fatigue factor applied to torsional moment

S_{yt} = Yield strength in tension

f_s = factor of safety(for shaft, take f_s = 6, for keys, f_s = 3)

Table 1: Nominal room temperature Yield and Tensile Strengths for annealed Austenitic Stainless Steels.								
AISI Type	301	304	304L	305	309S	310S	316	316L
Yield Strength (0.2% offset) MPa	275	290	270	262	310	310	290	290
Tensile Strength MPa	755	580	560	585	620	655	580	560

Table 2.10 Yield and Tensile Strength of Stainless Steel

Table 9.2 Values of shock and fatigue factors k_b and k_t

Application	k_b	k_t
(i) load gradually applied	1.5	1.0
(ii) load suddenly applied (minor shock)	1.5–2.0	1.0–1.5
(iii) load suddenly applied (heavy shock)	2.0–3.0	1.5–3.0

Table 2.11 Values of Shock and Fatigue factors

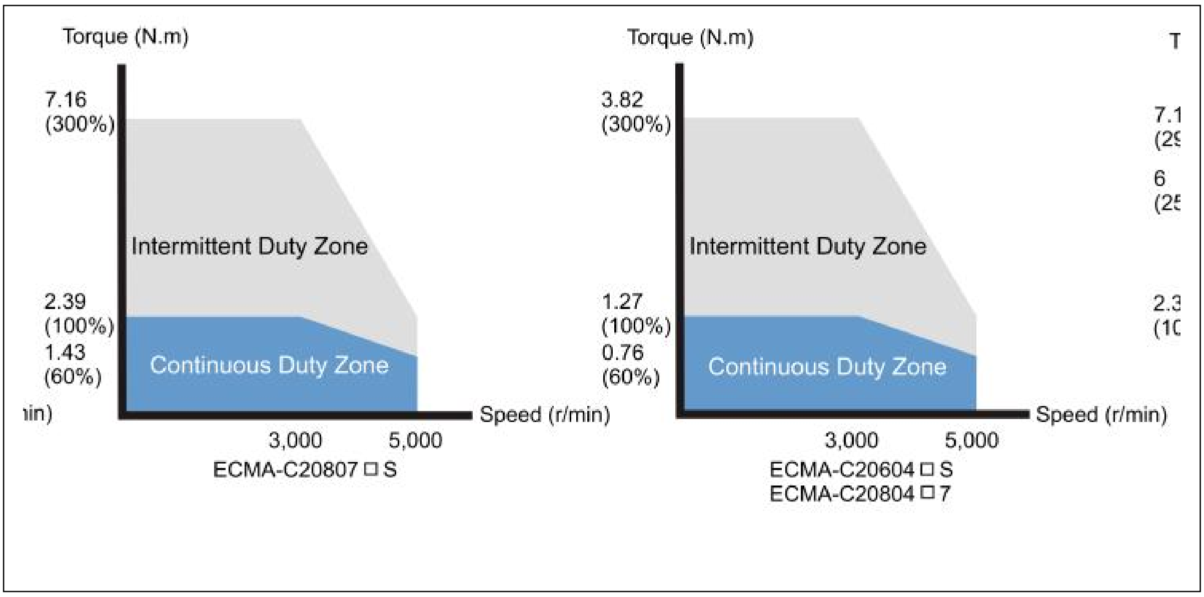


Fig 2.26 Torque Speed Characteristics of 0.75kW and 400W servo motors

Therefore,

Maximum Principle Stress, σ_1

$\sigma_1 = S_{yt}/(f_s) = (16/\pi d^3)\ \{k_bM_b + \sqrt{[(k_bM_b)^2 + (k_tM_t)^2]}\}$

$S_{yt}/(f_s) = (16/\pi d^3)\ \{k_bM_b + \sqrt{[(k_bM_b)^2 + (k_tM_t)^2]}\}$

$290*10^6/10 = (16/\pi d^3)\ \{2*5.7 + \sqrt{[(2*5.7)^2 + (1.5*10.74)^2]}\}$

d = 17.6mm

Therefore,

Maximum Shear Stress, τ_{max}

$Tmax/f_s = 0.23S_{yt} / f_s = (16/\pi d^3)\ \sqrt{[(k_bM_b)^2 + (k_tM_t)^2]}$

$(0.23 *290*10^6) /6 = (16/\pi d^3)\ \sqrt{[(2*5.7)^2 + (1.5*10.74)^2]}$

d = 20.8mm

Therefore according to the availability we can take shaft diameter as

d = 25 mm

2.3.2. Design of Keys

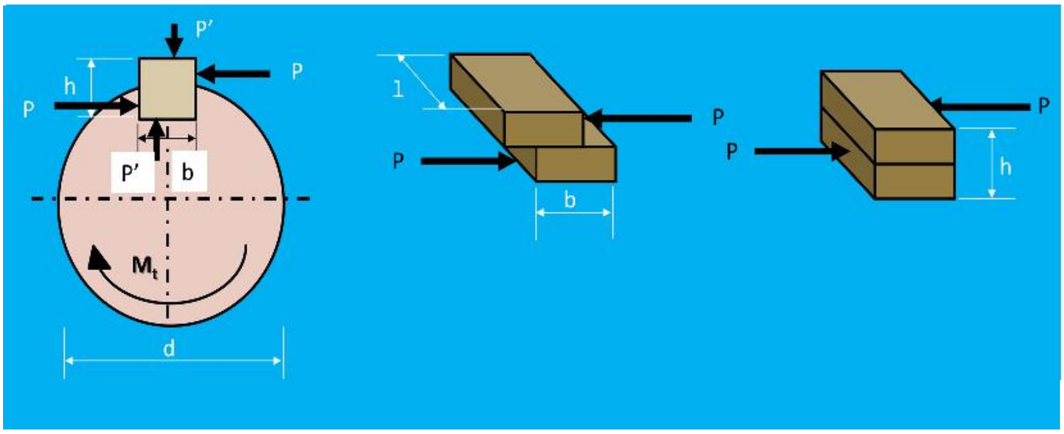


Fig 2.27 Forces on Shaft Key

Here, M_t = 10.74 Nm

P' = 104.2 N

d = 25 mm

p = $M_t/(d/2) = 2M_t/d$ = 859.2 N

Shear Stress, $\tau = S_{sy} / f_s$ = P/ (Shear area) = $859.2*10^6/(b.l)$, $S_{sy} = 0.5S_{yt}$

$0.5*290*10^6/3 = 859.2*10^6/(b.l)$

(b.l) = 17.8

For compressive stress, σ_c= P/ (crushing area)

$\sigma_c = P/ (h/2)*l = 2P/hl$

$\sigma_c = 4M_t/dhl$

$\sigma_c = S_{yt}/ f_s = 4M_t/dhl = 1718*10^6/hl$

$580*10^6/ 3 = 1718*10^6/hl$

hl = 8.9

From above two expressions take key size as 8x8x30mm

2.3.3. Selecting of coupling for shafts

Maximum torque on shaft , T_{max} = 10.74* f_sNm

Take factor of safety f_s= 2 for couplings

Therefore, T_{max} = 21.48 Nm

Shaft diameter = 25mm

Considering above factors "L095 coupling with NBR elastomeric member "is selected.

Size	Elastomeric Member	Number of Jaws	Basic HP Ratings @ Varying RPM				Torque Rating		Max Bore		Max x1000
			100	1200	1800	3600	in-lbs	Nm	in	mm	RPM
L, AL & LC Type											
L035	SOX (NBR)	2	0.006	0.07	0.10	0.22	3.5	0.40	0.375	9	31.0
L050/AL050	SOX (NBR)	2	0.042	0.50	0.75	1.51	26.3	2.97	0.625	16	18.0
L050/AL050	Hytrel®	2	0.080	0.96	1.43	2.88	50.0	5.65	0.625	16	18.0
L070/AL070	SOX (NBR)	2	0.070	0.84	1.23	2.52	43.2	4.88	0.750	19	14.0
L070/AL070	Hytrel	2	0.180	2.16	3.26	6.48	114.0	12.88	0.750	19	3.6
L075/AL075	SOX (NBR)	3	0.140	1.68	2.57	5.04	90.0	10.17	0.875	22	11.0
L075/AL075	Hytrel	3	0.360	4.32	6.48	12.96	227.0	25.65	0.875	22	3.6
L090/AL090/LC090	SOX (NBR)	3	0.230	2.76	4.11	8.28	144.0	16.27	1.000	25	9.0
L090/AL090	Hytrel	3	0.640	7.68	11.50	23.04	401.0	42.31	1.000	25	3.6
L095/AL095/LC095	SOX (NBR)	3	0.310	3.72	5.50	11.16	194.0	21.92	1.125	32	9.0
L095/AL095	Hytrel	3	0.890	10.68	16.00	32.04	561.0	63.38	1.125	32	3.6
L099/AL099/LC099	SOX (NBR)	3	0.500	6.00	9.10	18.00	318.0	35.93	1.180	30	7.0
L099/AL099	Hytrel	3	1.260	15.12	22.60	45.36	792.0	89.48	1.180	30	3.6
L100/AL100/LC100	SOX (NBR)	3	0.660	7.92	11.90	23.76	417.0	47.11	1.380	35	7.0
L100/AL100	Hytrel	3	1.800	21.60	32.40	64.80	1,134.0	128.12	1.380	35	3.6
L110/AL110/LC110	SOX (NBR)	3	1.260	15.12	23.00	45.36	792.0	89.48	1.620	42	5.0
L110/AL110	Hytrel	3	3.600	43.20	65.00	129.60	2,268.0	256.25	1.620	42	5.0
L150/LC150	SOX (NBR)	3	2.000	24.00	35.00	72.00	1,240.0	140.10	1.880	48	5.0
L150	Hytrel	3	5.900	70.80	106.00	212.40	3,708.0	418.95	1.880	48	5.0
AL-150	SOX (NBR)	4	2.300	27.60	41.40	82.80	1,450.0	163.83	1.880	48	5.0
L190/LC190	SOX (NBR)	3	2.700	32.40	49.00	97.20	1,728.0	195.24	2.120	55	5.0
L190	Hytrel	3	7.400	88.80	134.00	266.40	4,680.0	528.77	2.120	55	5.0
L225/LC225	SOX (NBR)	3	3.700	44.40	67.00	133.20	2,340.0	264.38	2.620	65	4.2
L225	Hytrel	3	9.900	118.80	178.00	356.40	6,228.0	703.67	2.620	65	4.2
L276	SOX (NBR)	3	7.500	90.00	135.00	+	4,716.0	532.84	2.880	73	1.8

Table 2.12 Jaw Coupling Specifications

3.0 DEVELOPMENT OF THE MACHINE

3.1 Mechanical Drawings

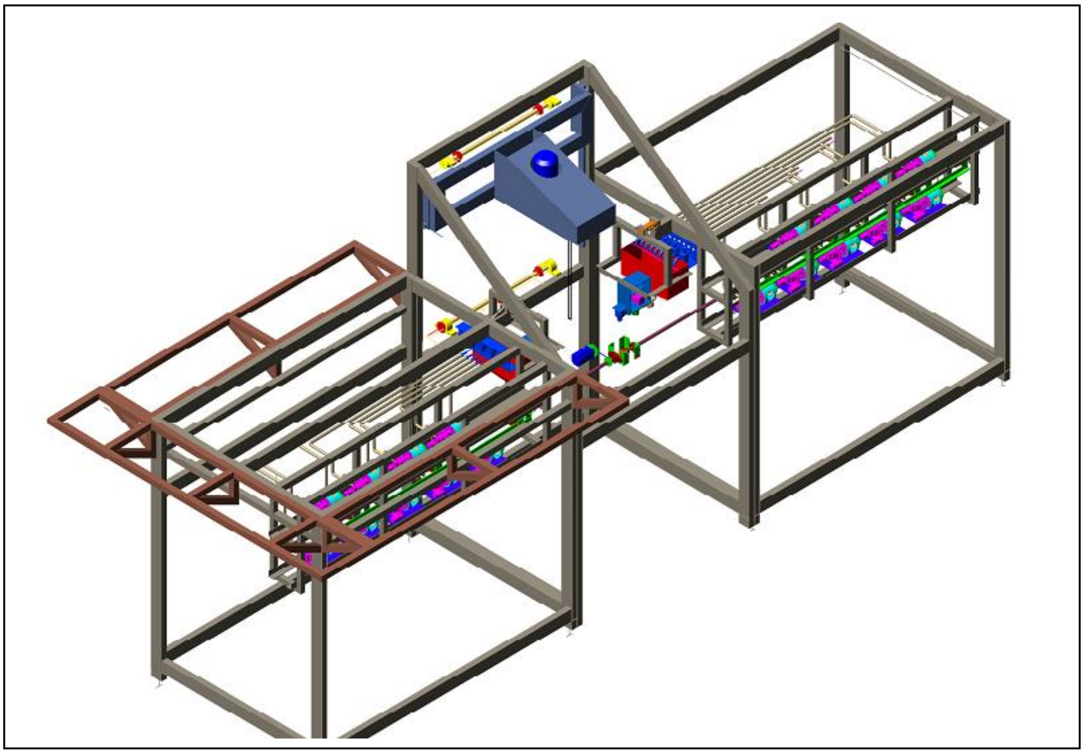


Fig 3.1 3D View of Overall Machine

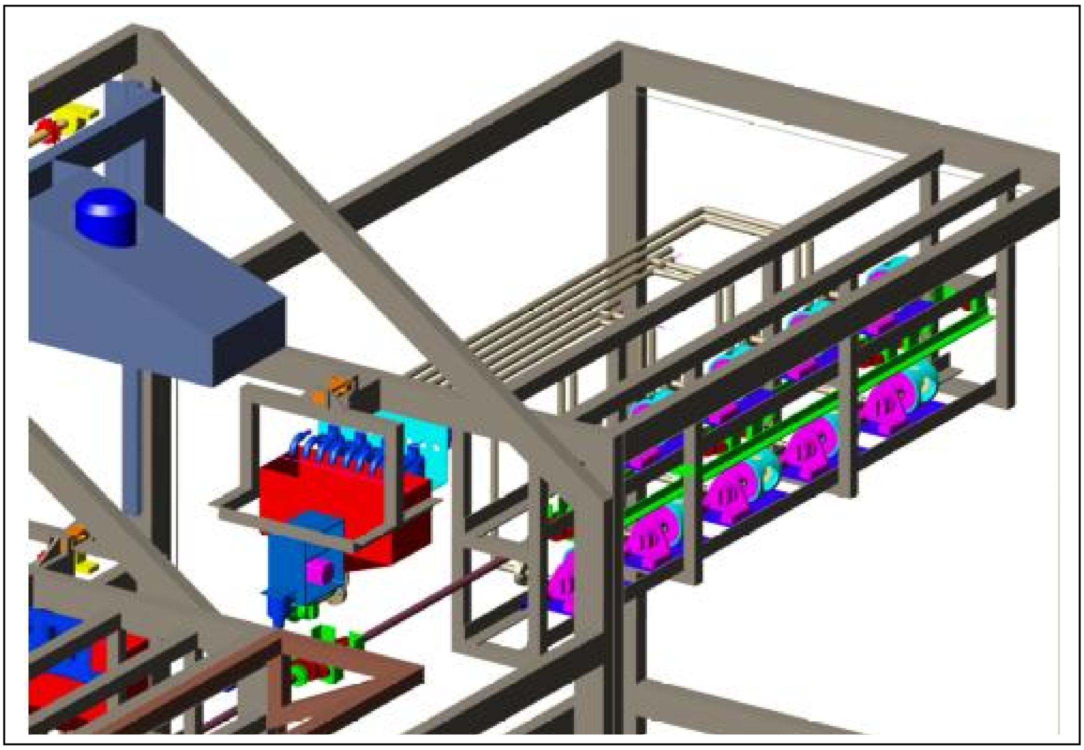


Fig 3.2 Close-up View of Mixing Head, Collecting Tank, and Pumps

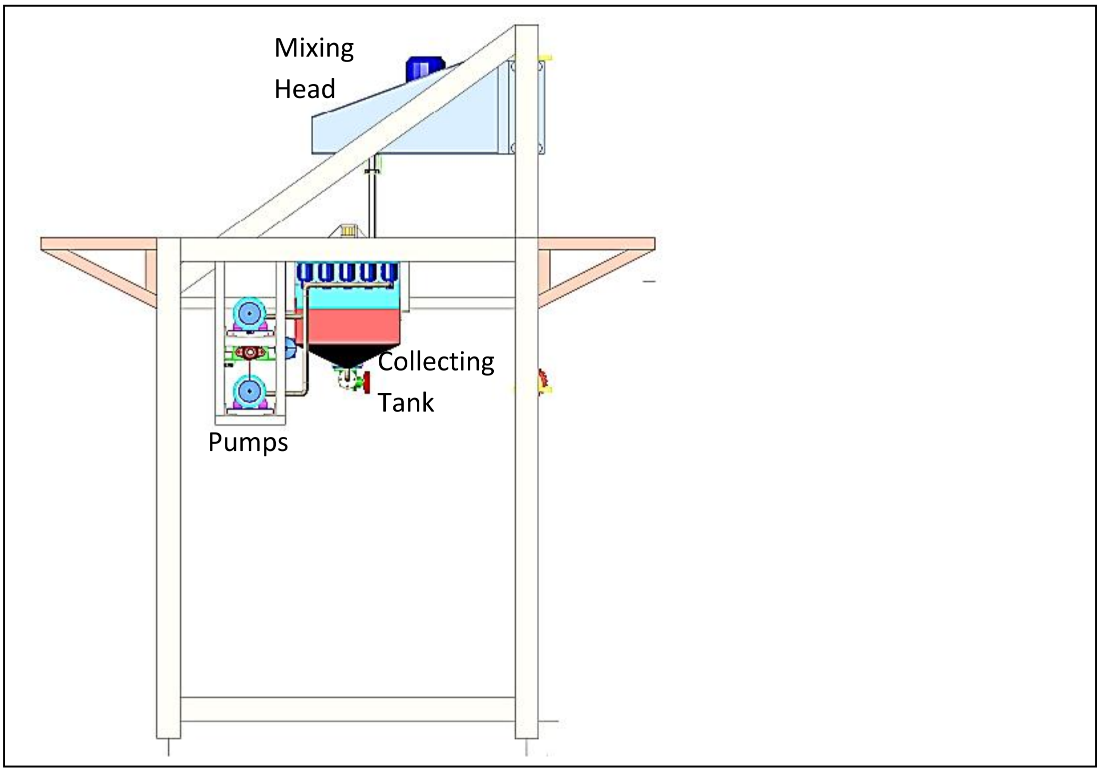


Fig 3.3 End Elevation of the Machine

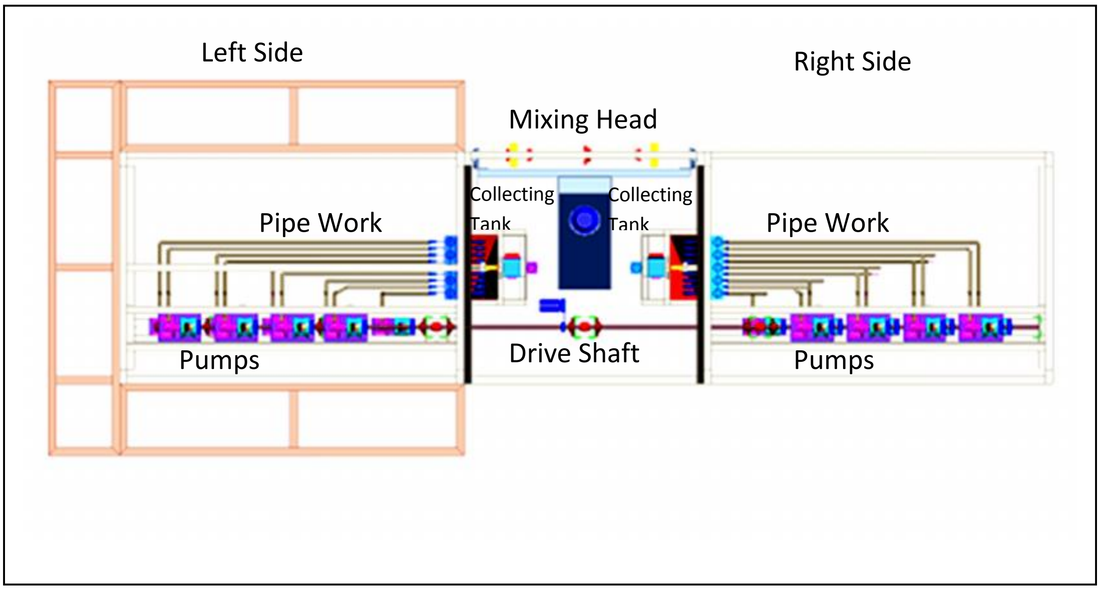


Fig 3.4 Plan of the Machine

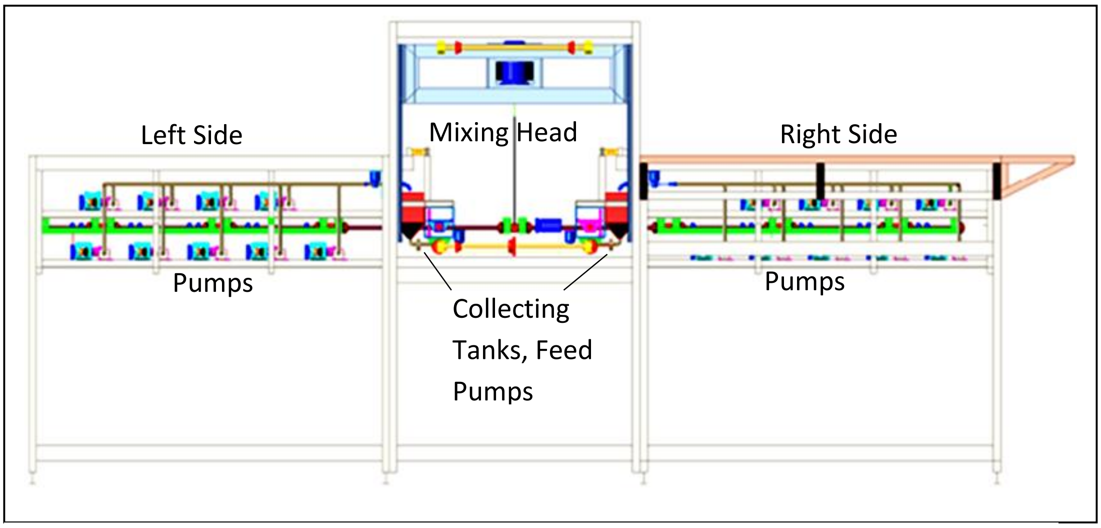


Fig 3.5 Front Elevation of the Machine

3.2. Electrical Drawings

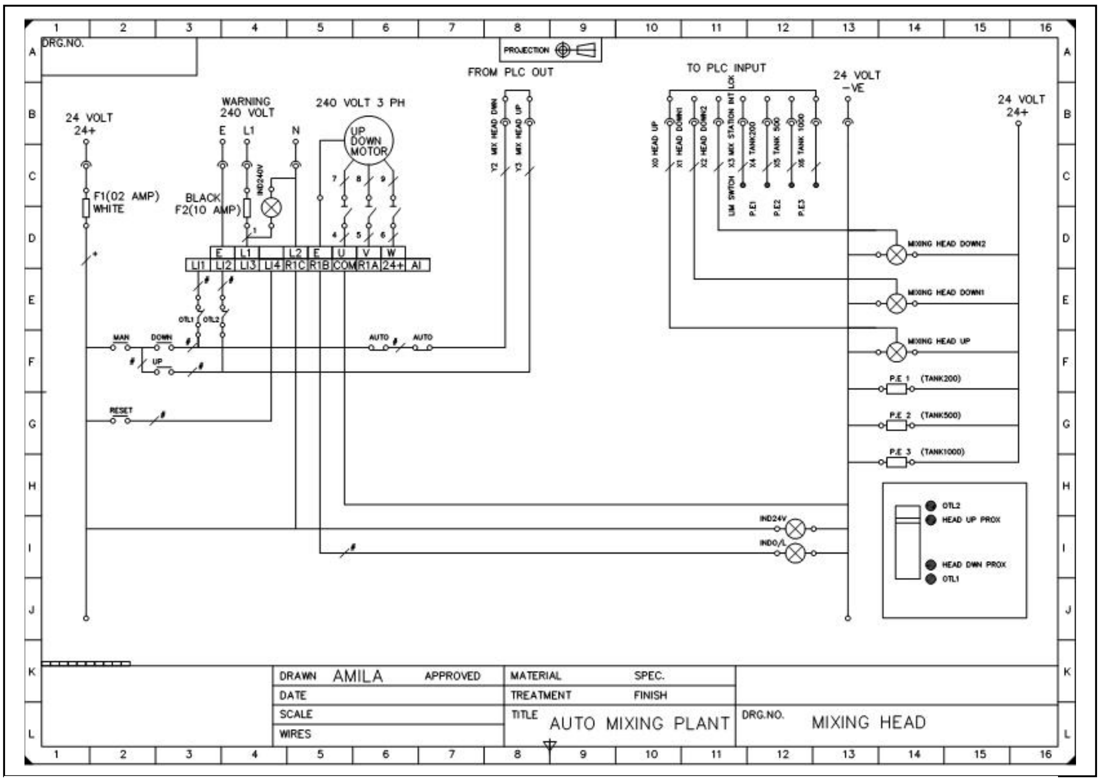


Fig 3.6 Circuit Diagram of Mixing Head

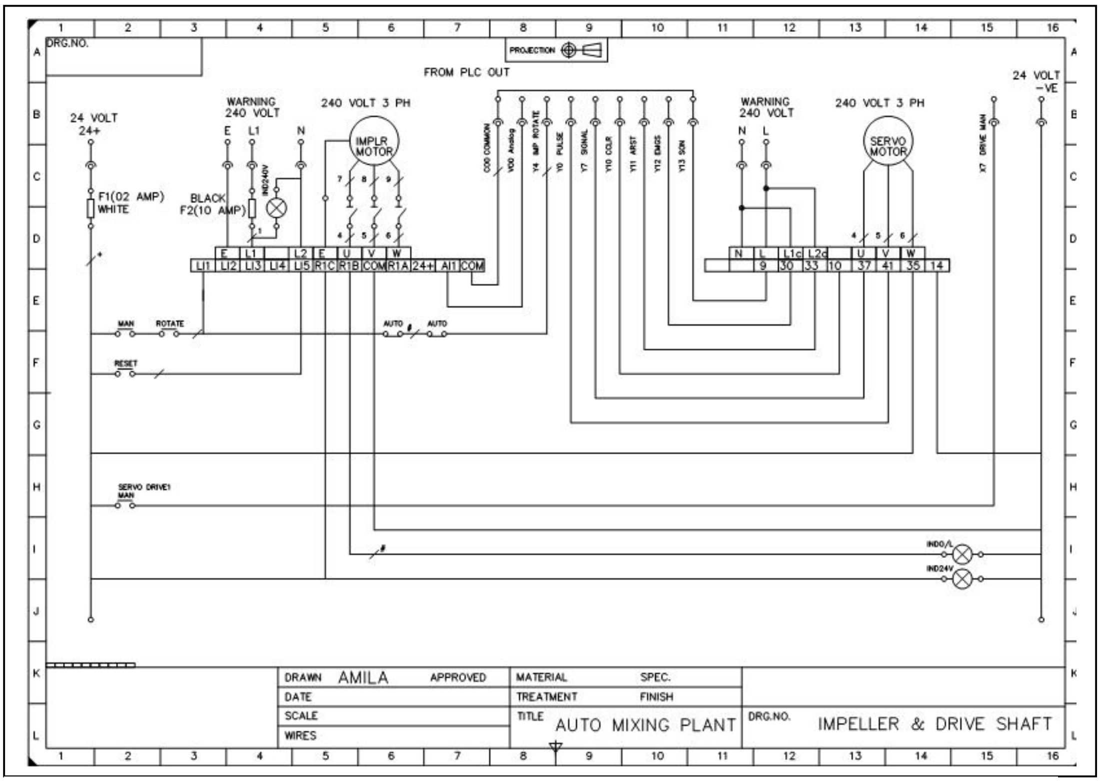


Fig 3.7 Circuit Diagram of Impeller and Drive Shaft

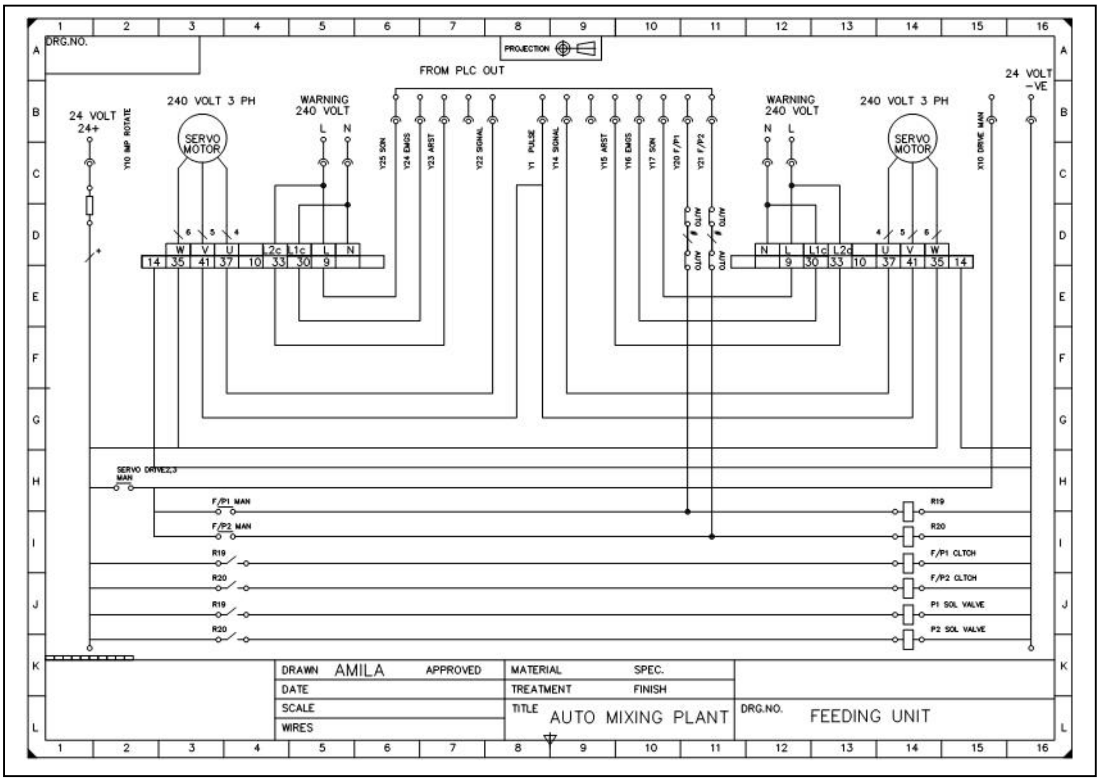


Fig 3.8 Circuit Diagram of Chemical Feeding Unit

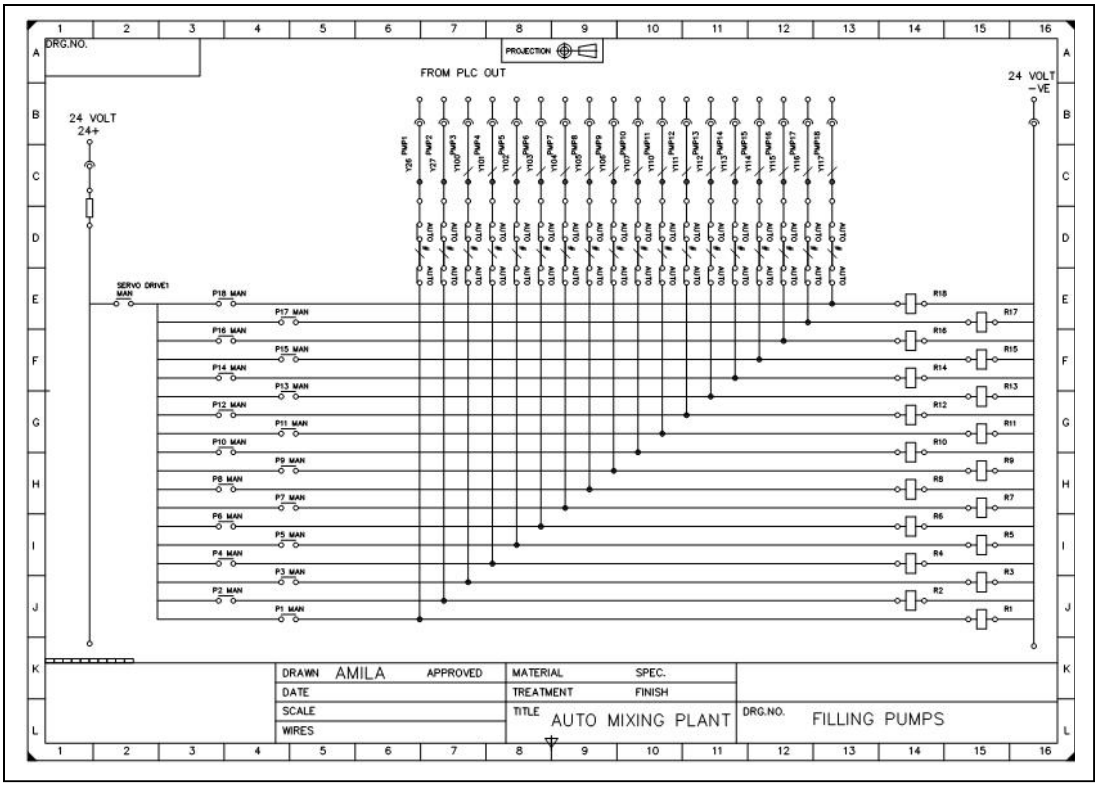


Fig 3.9 Circuit Diagram of Filling Pumps

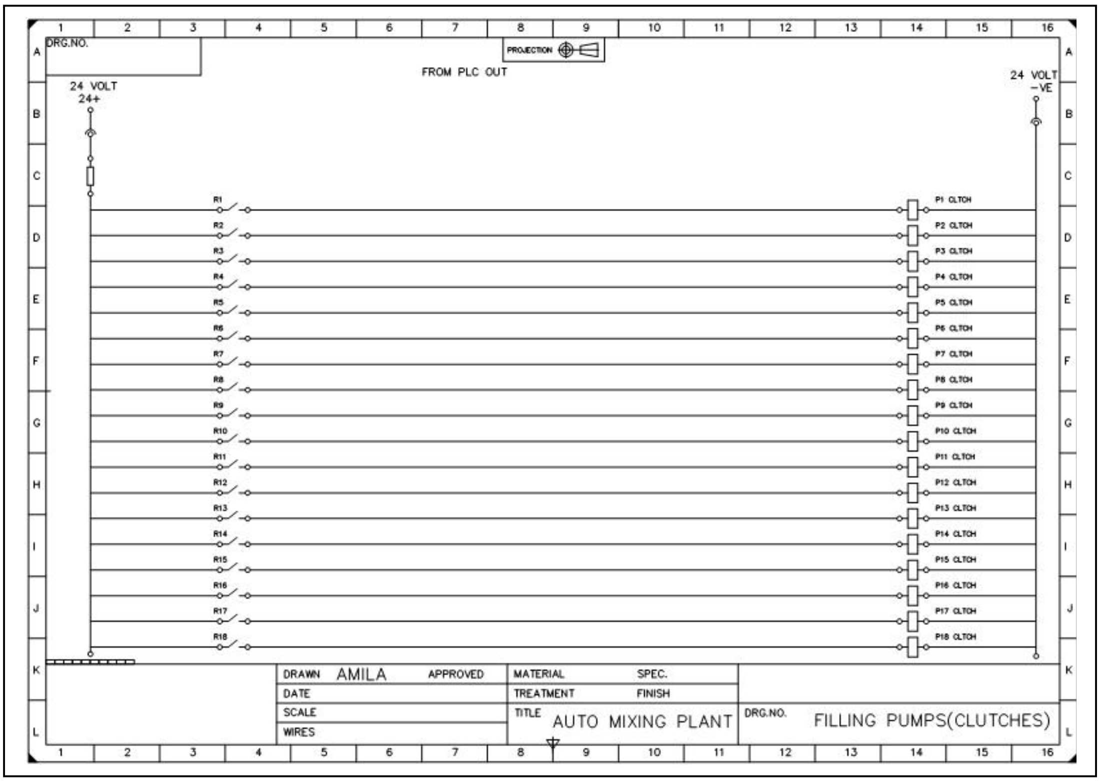


Fig 3.10 Circuit Diagram of Filling Pump Clutches

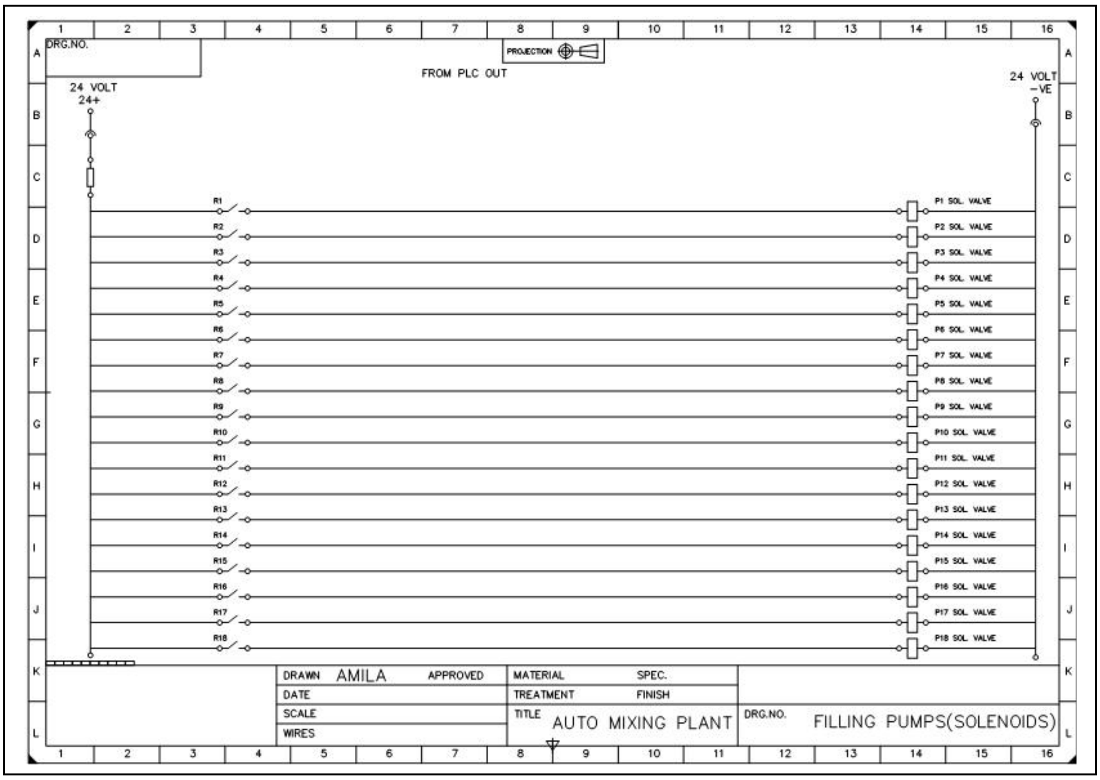


Fig 3.11 Circuit Diagram of Filling Pump Solenoid Valves

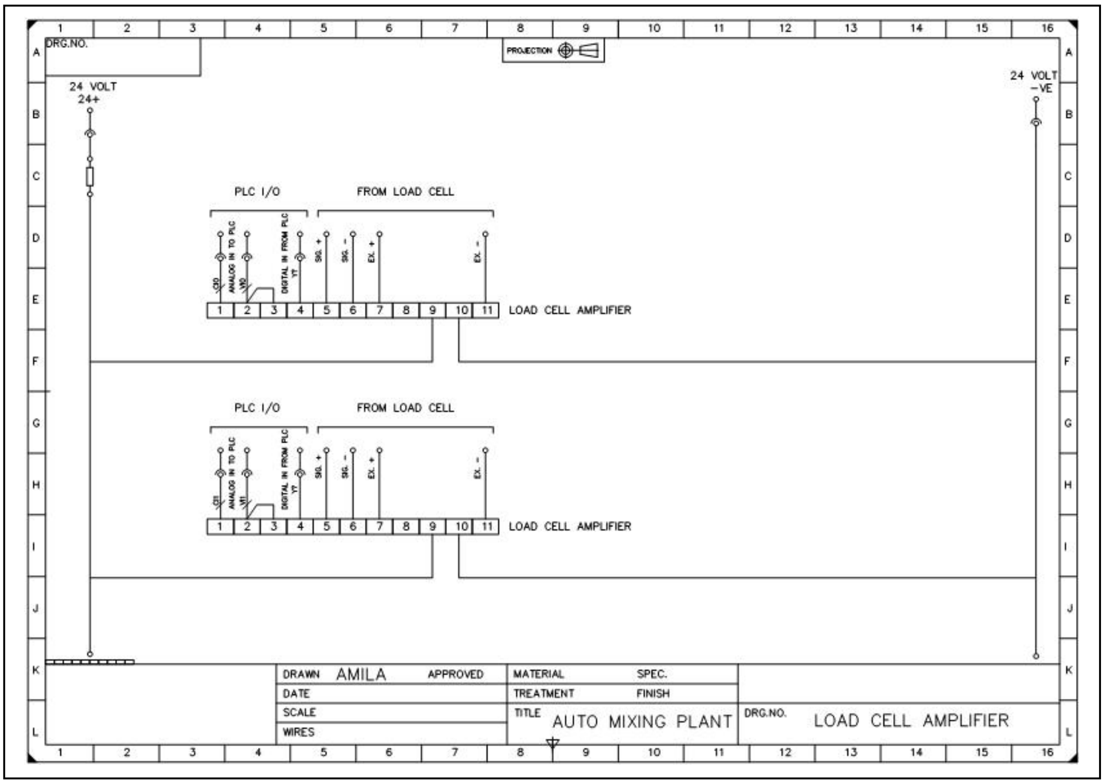


Fig 3.12 Circuit Diagram of Load Cell Amplifier

3.3. Fabrication Work

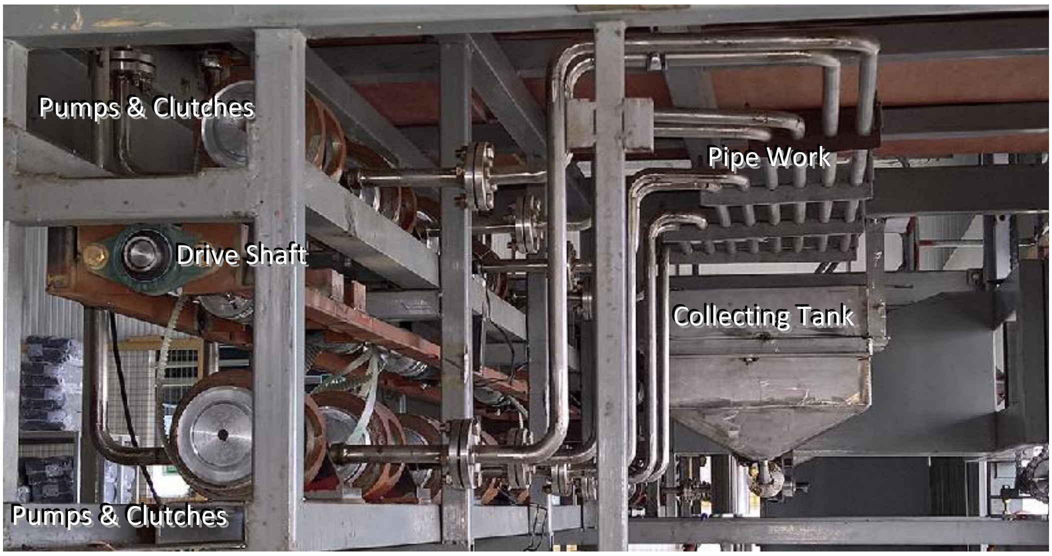


Fig 3.13 Close View of Collecting Tank, Pumps and Pipe Work

Fig 3.14 Pumps, Clutches and Drive Shaft-View from Front

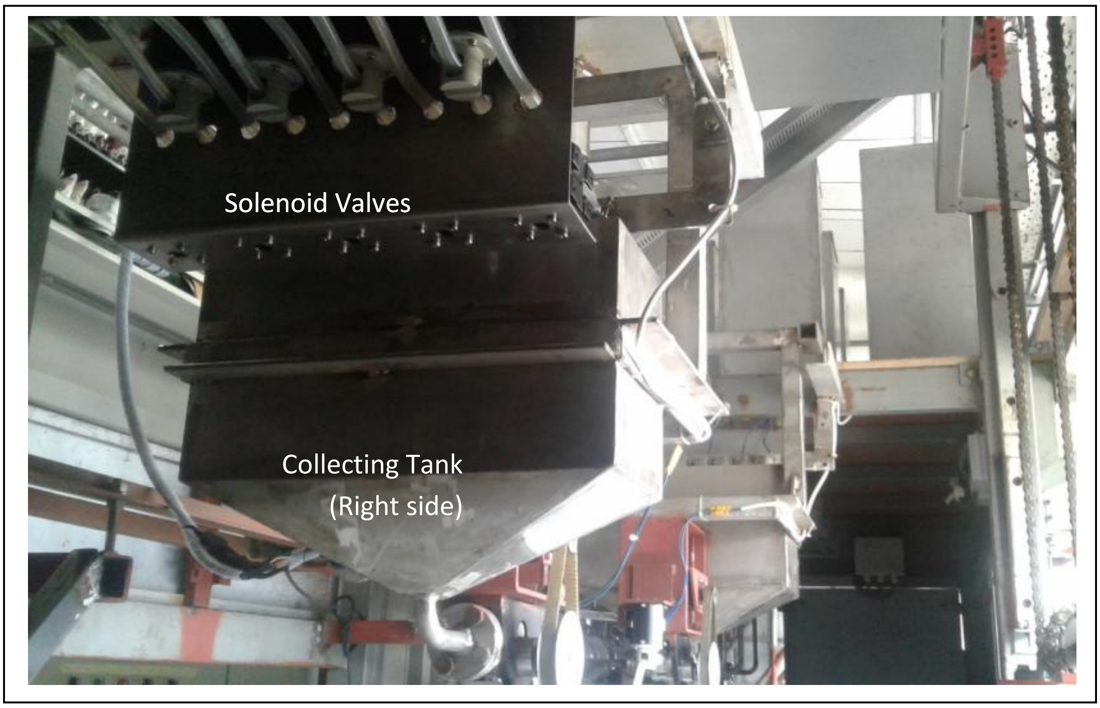


Fig 3.15Close View of Collecting Tanks, Feeding Pumps and Solenoid Valves

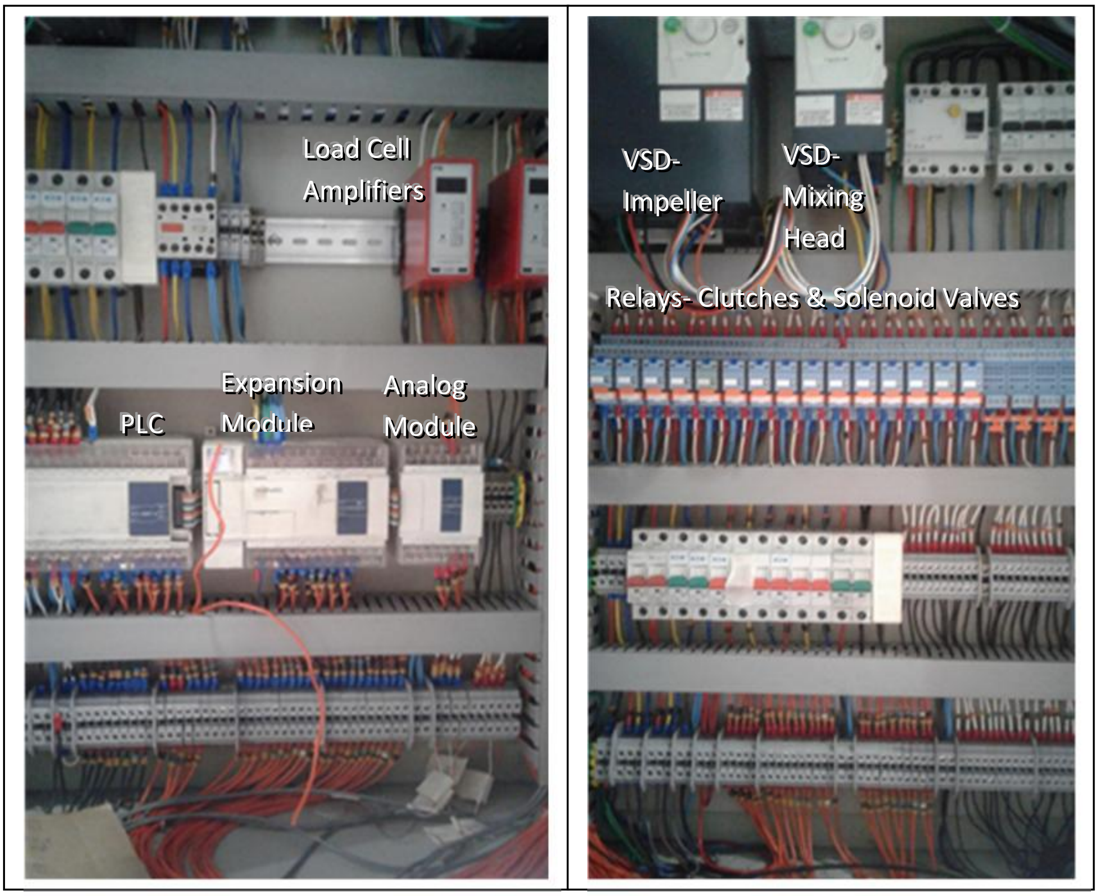


Fig 3.16 Control Panels

Fig 3.17 Control Panels-Outside View

Fig 3.18 View of Complete Machine

3.4. Programming

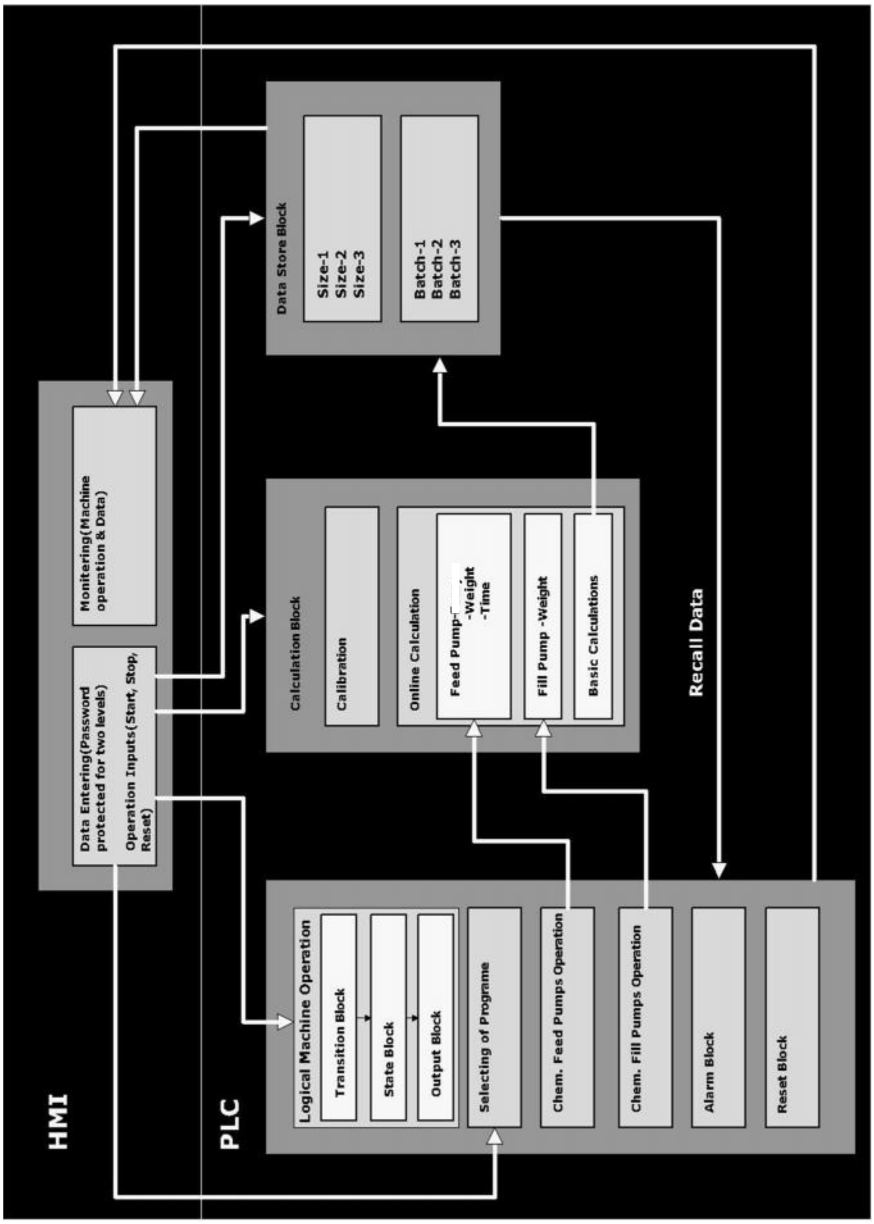


Fig 3.19 Programming Structure

As far as the programing structure in Fig 3.19 is concerned it can be seen that the PLC and the HMI unit are interconnected. The HMI is compatible with the PLC and XINJE, XC3-60RT-E PLC was programed using MCP-XCPPro3.1 ladder logic software and XINJE, TH765-N touch panel was programmed using TouchWin software.

When the PLC program structure is concerned three major areas can be identified. The overall machine operation block, Calculation block and the Data storing block. The machine operation block comprises of logical machine operation block which is programed according to the state based design, program selection block, feed pumps and fill pump operation blocks, alarming block and the machine reset block. The calculation block comprises of calibration block and the online calculation block. The data store block stores all the data related to the all types of batch sizes which can be entered and modified by an authorized personal. Some data (required flow rate) are stored after a simple calculation done by the basic calculation block. These stored data are recalled when selecting the program and stored in temporary registers at machine operation block. The program selecting inputs, start and stop inputs are written in the ladder logic machine operation program block and they can be accessed via the HMI. According to the front touch panel inputs the machine starts operation. The online calculations required regarding the feed pump and fill pumps operations are done by the online calculation block according to the load cell feedback signal. Three parameters are continuously calculated while running the machine at feed pump calculation block. They are speed of the feed pump, reducing weight at the bucket and the changing of feeding time. An algorithm has been developed to keep the feeding flow rate constant by varying the pulse input to the servo drive. The fill pump online calculation block calculates the filling weight of the chemical according to the load cell feedback signal.

If there is a fault while running the machine alarming messages are programmed at the alarm block such a way that to display them at a fault and stop the machine until the fault is rectified.

In case of programming the HMI it should be programmed basically for two purposes. They are data and input entering purpose and data and output monitoring purpose. The PLC registers and inputs can be programmed at front screen as digital inputs and push buttons. Also PLC registers, memory flags and outputs can be programmed as digital outputs and indicators. Furthermore TouchWin software provides multiple page programming facility, password protection facility and animation facility by enhancing smart programming. Therefore user friendly front panel programming is possible.

3.4.1. State based ladder logic programing

The state based ladder logic program design steps are as below.

- Step 1-Linguistic Model
- Step 2-Inputs/Outputs
- Step 3-State Transition Diagram
- Step 4-Output Table
- Step 5-Ladder Logic Program

Linguistic Model

The linguistic model is a step by step logical description of the machine operation sequence. In this case there are 86 steps to be completed for the complete machine operation.

1) When Compound Type, Batch Size, Tank Position, Mixing Head Top Position proximity sensor and Machine On signals present, Mixing head will move down to Mixing head down proximity limit.

2) When mixing head comes to down proximity, Mixing head stops, impeller will start to rotate at given speed for premix time. Pump1 (Left Side) will run.

3) Pump1 (Left Side) will stop according to the load cell (L/F) signal.

4) After the premix time, impeller speed will change Chemical 1 (L/S) will run P2(R/S) will run

5) Chemical 1 (L/S) will run fast according to load cell (L/S) signal

6) Chemical 1 (L/S) will stop according to time

7) P2(R/S) will stop according to the load cell(R/S) signal.

8) After C1 (L/S) and P2(R/S) stop, impeller speed will change C2 (R/S) will run P3 (L/S) will run

9) C2 (R/S) will fast run according to load cell(R/S) signal

10) C2 (R/S) will stop according to time

11) P3 (L/S) will stop according to the load cell (L/S) signal.

12) After C2(R/S) and P3 (L/S) stop, impeller speed will change C3 (L/S) will run P4 (R/S) will run

13) C3 (L/S) will fast run according to load cell (L/S) signal

14) C3 (L/S) will stop according to time

15) P4(R/S) will stop according to the load cell(R/S) signal.

16) After C3 (L/S) and P4(R/S) stop, impeller speed will change C4 (R/S) will run P5 (L/S) will run

17) C4 (R/S) will fast run according to load cell(R/S) signal

18) C4 (R/S) will stop according to time

19) P5 (L/S) will stop according to the load cell (L/S) signal.

20) After C4(R/S) and P5 (L/S) stop, impeller speed will change C5 (L/S) will run P6 (R/S) will run

21) C5 (L/S) will fast run according to load cell (L/S) signal

22) C5 (L/S) will stop according to time

23) P6(R/S) will stop according to the load cell(R/S) signal.

24) After C5 (L/S) and P6(R/S) stop, impeller speed will change C6 (R/S) will run P7 (L/S) will run

25) C6 (R/S) will fast run according to load cell(R/S) signal

26) C6 (R/S) will stop according to time

27) P7(L/S) will stop according to the load cell(L/S) signal.

28) After C6(R/S) and P7 (L/S) stop, impeller speed will change C7 (L/S) will run P8 (R/S) will run

29) C7 (L/S) will fast run according to load cell (L/S) signal

30) C7 (L/S) will stop according to time

31) P8(R/S) will stop according to the load cell(R/S) signal.

32) After C7 (L/S) and P8(R/S) stop, impeller speed will change C8 (R/S) will run P9 (L/S) will run

33) C8 (R/S) will fast run according to load cell(R/S) signal

34) C8 (R/S) will stop according to time

35) P9 (L/S) will stop according to the load cell (L/S) signal.

36) After C8(R/S) and P9 (L/S) stop, impeller speed will change C9 (L/S) will run P10 (R/S) will run

37) C9 (L/S) will fast run according to load cell (L/S) signal

38) C9 (L/S) will stop according to time

39) P10(R/S) will stop according to the load cell(R/S) signal.

40) After C9 (L/S) and P10(R/S) stop, impeller speed will change C10 (R/S) will run P11 (L/S) will run

41) C10 (R/S) will fast run according to load cell(R/S) signal

42) C10 (R/S) will stop according to time

43) P11 (L/S) will stop according to the load cell (L/S) signal.

44) After C10(R/S) and P11 (L/S) stop, impeller speed will change C11 (L/S) will run P12 (R/S) will run

45) C11 (L/S) will fast run according to load cell (L/S) signal

46) C11 (L/S) will stop according to time

47) P12(R/S) will stop according to the load cell(R/S) signal.

48) After C9 (L/S) and P10(R/S) stop, impeller speed will change C10 (R/S) will run P11 (L/S) will run

49) C10 (R/S) will fast run according to load cell(R/S) signal

50) C10 (R/S) will stop according to time

51) P11 (L/S) will stop according to the load cell(L/S) signal.

52) After C10(R/S) and P11 (L/S) stop, impeller speed will change C11 (L/S) will run P12 (R/S) will run

53) C11 (L/S) will fast run according to load cell (L/S) signal

54) C11 (L/S) will stop according to time

55) P12(R/S) will stop according to the load cell(R/S) signal.

56) After C11 (L/S) and P12(R/S) stop, impeller speed will change C12 (R/S) will run P13 (L/S) will run

57) C12 (R/S) will fast run according to load cell(R/S) signal

58) C12 (R/S) will stop according to time

59) P13 (L/S) will stop according to the load cell (L/S) signal.

60) After C12(R/S) and P13 (L/S) stop, impeller speed will change C13 (L/S) will run P14 (R/S) will run

61) C13 (L/S) will fast run according to load cell (L/S) signal

62) C13 (L/S) will stop according to time

63) P14(R/S) will stop according to the load cell(R/S) signal.

64) After C13 (L/S) and P14(R/S) stop, impeller speed will change C14 (R/S) will run P15 (L/S) will run

65) C14 (R/S) will fast run according to load cell(R/S) signal

66) C14 (R/S) will stop according to time

67) P15 (L/S) will stop according to the load cell (L/S) signal.

68) After C14(R/S) and P15 (L/S) stop, impeller speed will change C15 (L/S) will run P16 (R/S) will run

69) C15 (L/S) will fast run according to load cell (L/S) signal

70) C15 (L/S) will stop according to time

71) P16(R/S) will stop according to the load cell(R/S) signal.

72) After C15 (L/S) and P16(R/S) stop, impeller speed will change C16 (R/S) will run P17 (L/S) will run

73) C16 (R/S) will fast run according to load cell(R/S) signal

74) C16 (R/S) will stop according to time

75) P17 (L/S) will stop according to the load cell (L/S) signal.

76) After C16(R/S) and P17 (L/S) stop, impeller speed will change C17 (L/S) will run P18 (R/S) will run

77) C17 (L/S) will fast run according to load cell (L/S) signal

78) C17 (L/S) will stop according to time

79) P18(R/S) will stop according to the load cell(R/S) signal.

80) After C17 (L/S) and P18(R/S) stop, impeller speed will change C18 (R/S) will run

81) C18 (R/S) will fast run according to load cell(R/S) signal

82) C18 (R/S) will stop according to time

83) After C18(R/S) stops, impeller speed will change and run for post mix time

84) After post mix time Impeller will stop

85) After Impeller stops Mix head will move up until top proximity

86) After all pumps stop, all chemical stop and head at top machine will stop

Step-2 Inputs and outputs

PLC (XC3-60RT-E)

INPUTS

X0	Mixing head up(proximity)
X1	Mixing head down1(Proximity)
X2	Mixing head down2(Proximity)
X3	Mixing station interlock(Limit Switch)
X4	Tank 200(Photo sensor)
X5	Tank 500(Photo sensor)
X6	Tank 1000(Photo Sensor)
VI0	Load cell amplifier signal

OUTPUTS

Y0	Pulse-Filling Pump Drive	Y26	PMP1 (Relay
Y1	Pulse-Feeding Pump Drive	Y27	PMP2 (Relay
Y2	Mixing Head Down	Y100	PMP3 (Relay
Y3	Mixing Head Up	Y101	PMP4 (Relay
Y4		Y102	PMP5 (Relay
Y5		Y103	PMP6 (Relay
Y6		Y104	PMP7 (Relay
Y7	SIGNAL	Y105	PMP8 (Relay
Y10	CCLR	Y106	PMP9 (Relay
Y11	ARST	Y107	PMP10 (Rela
Y12	EMGS	Y110	PMP11 (Rela
Y13	SON	Y111	PMP12 (Rela
Y14	SIGNAL	Y112	PMP13 (Rela
Y15	ARST	Y113	PMP14 (Rela
Y16	EMGS	Y114	PMP15 (Rela
Y17	SON	Y115	PMP16 (Rela
Y20	F/P1	Y116	PMP17 (Rela
Y21	F/P2	Y117	PMP18 (Rela
Y22	SIGNAL	VO0	VSD(Impelle
Y23	ARST		
Y24	EMGS		
Y25	SON		

Fig 3.20 PLC Inputs and Outputs

Step-3, State Transition Diagram

The state transition diagram is drawn considering the linguistic model and inputs and outputs. Fig 3.21 shows the states from machine starting to end of fill pump 3 operation. There onwards other pump operation states are same until the final pump operation. The Fig 3.22 shows final steps of the machine operation.

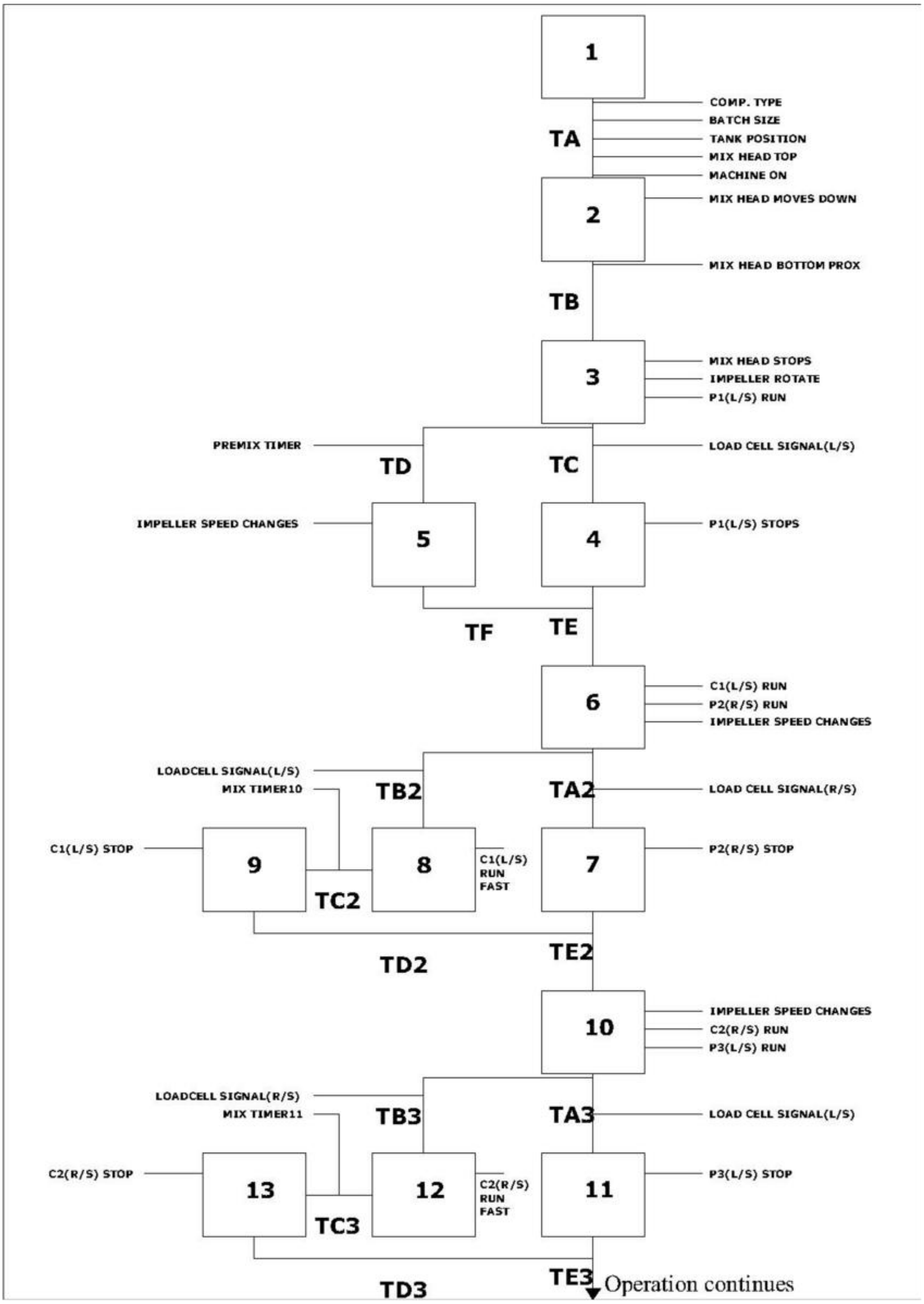


Fig 3.21 State Transition Diagram-From starting to fill pump 3 operation

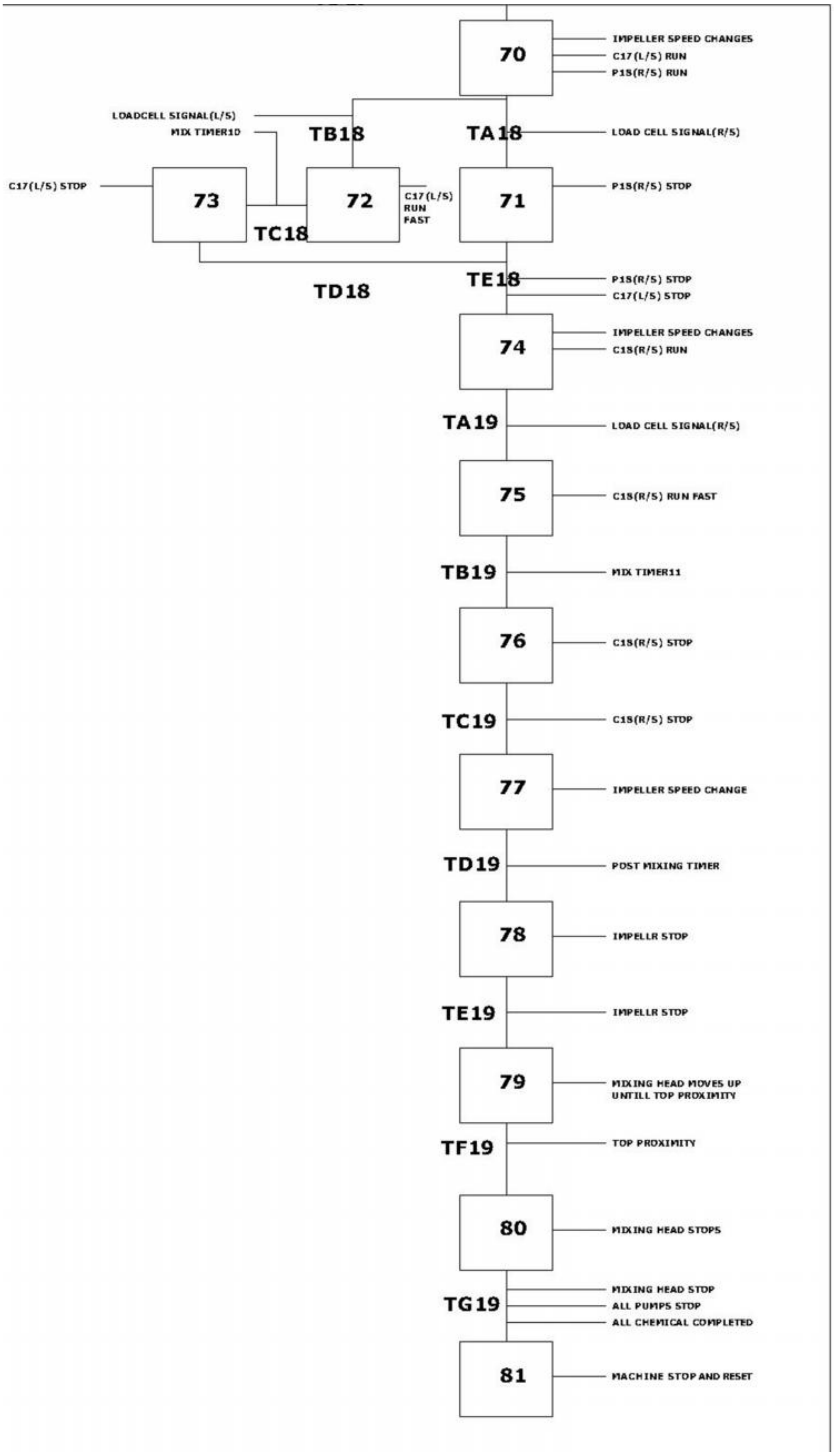


Fig 3.22 State Transition Diagram-Final steps of machine operation

Step-4 Input Output Table.

From the State Transition diagram the Output table is developed. There are all together 98 output steps to be considered with respect to 81 states when developing the output table. Therefore a part of the output table is shown in Fig 3.23.

Output \ State	1	2	3	4	5	6	7
MIX HEAD MOVES DOWN	0	1	0	0	0	0	0
MIX HEAD STOPS	0	0	1	0	0	0	0
IMPELLER ROTATE	0	0	1	0	0	0	0
P1(L/S) RUN	0	0	1	0	0	0	0
P1(L/S) STOPS	0	0	0	1	0	0	0
IMPELLER SPEED CHANGES	0	0	0	0	1	0	0
C1(L/S) RUN	0	0	0	0	0	1	0
P2(R/S) RUN	0	0	0	0	0	1	0
P2(R/S) STOP	0	0	0	0	0	0	1
C1(L/S) RUN FAST	0	0	0	0	0	0	0
C1(L/S) STOP	0	0	0	0	0	0	0
C2(R/S) RUN	0	0	0	0	0	0	0
P3(L/S) RUN	0	0	0	0	0	0	0
P3(L/S) STOP	0	0	0	0	0	0	0
C2(R/S) RUN FAST	0	0	0	0	0	0	0

Fig 3.23 Part of The Output Table

Step-5, Ladder logic program.

The ladder logic program is developed considering the state transition diagram and the output table. A part of the program is shown in Fig 3.24.

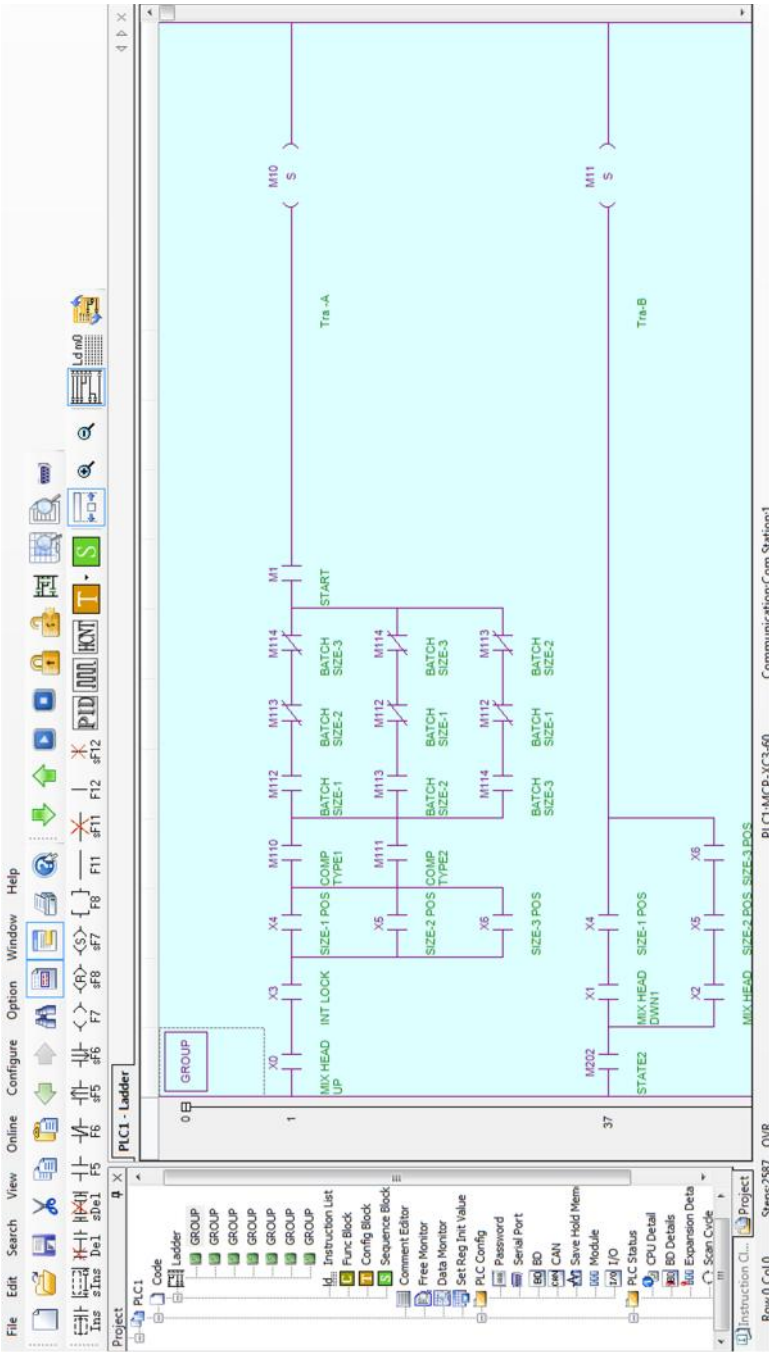


Fig 3.24 Part of the PLC program

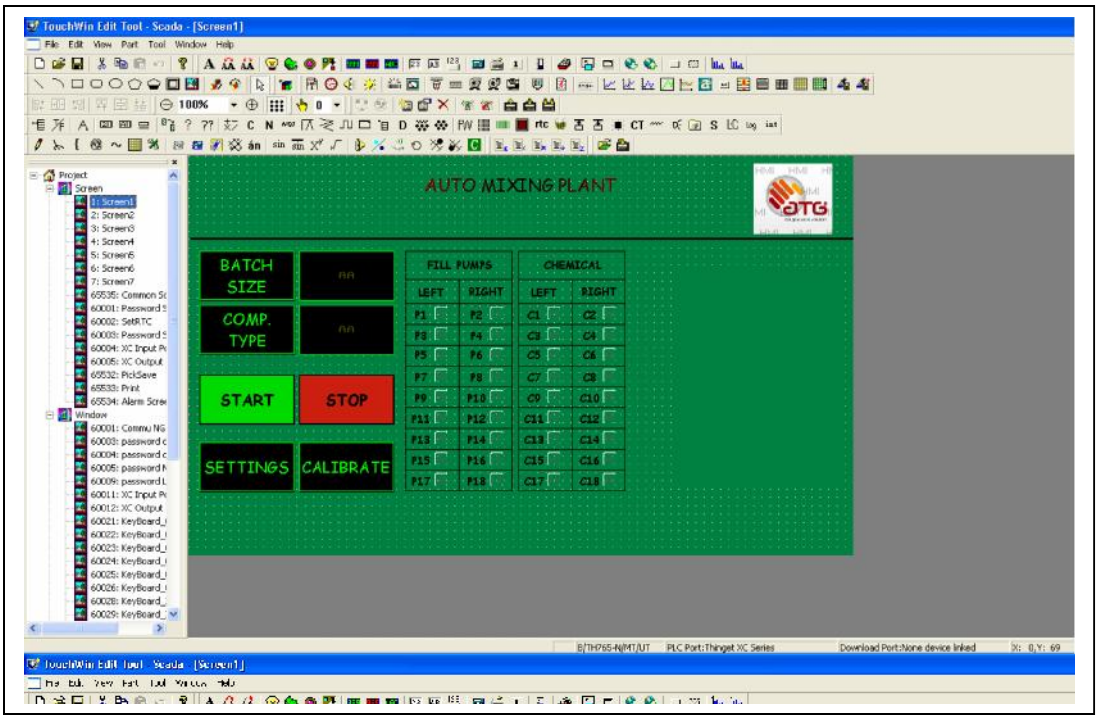


Fig 3.25 One of the Pages of Touch Panel Program

4.0. RESULTS

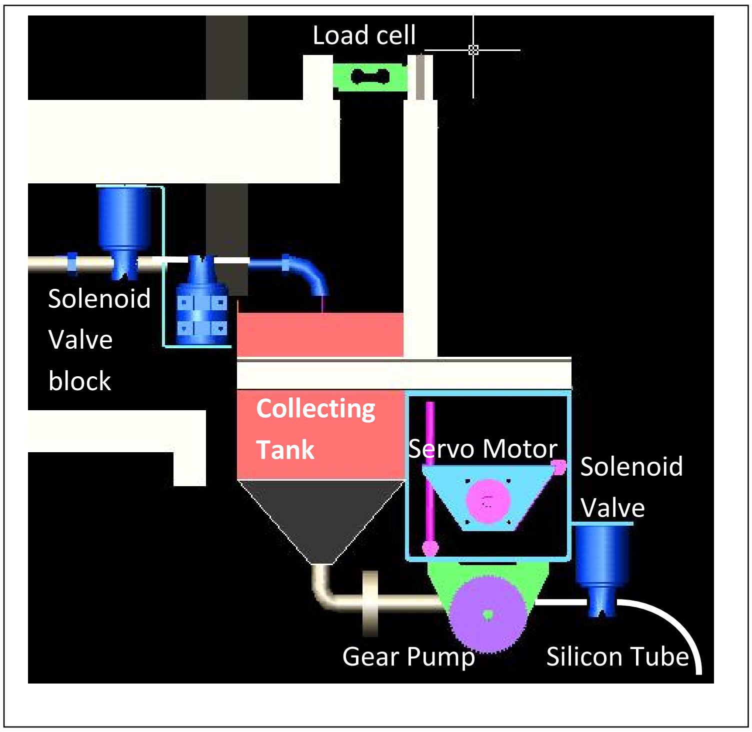


Fig 4.1Weighing System (Left Side)

Finally the two weighing systems (which consist of chemical collecting tank hanged on the load cell, servo motor driven gear pump attached to the collecting tank, load cell amplifier and PLC analog module) were calibrated according to the calibration procedure given in the load cell amplifier manual. Also a standard weight of 15kg was used in calibration.

After calibrating the system several trials were done and the system was fine-tuned (PLC Program).

From the HMI unit (Touchwin touch panel) weight and time parameters were entered for a batch size and the system was operated. First the mixing head moved down and mixing impeller started to rotate for the preset time (premix time) and at the same time the filling motor started and clutch and solenoid valve relevant to first pump were engaged and the set weight was measured. After the pre-mix time filled chemical at the left side collecting tank started to feed to the mixing tank and the second chemical was started to fill at the right side collecting tank. Here the feeding chemicals to the mixing tank were separately collected without disturbing the system for the purpose of assuring the measured weight. Likewise these measured chemicals by the machine, were reweighed by using a standard calibrated electronic balance and the values were tabulated. After finishing the feeding of eighteen chemicals the mixing impeller run for post mixing time (preset) and stopped. Then the mixing head moved up and whole the process was stopped. Therefore the operation of the machine was succeeded and the tabulated values were analyzed. According to the manual compounding process it is standardized that 1% error in weighing is allowable. Based on this according to the Table 4.1 it can be seen that except one chemical others are within the allowable limit.

Final test results are shown in Table 4.1

Chemical	Set Weight/(g)	Left Side			Right Side		
		Indicated Weight/(g) (displayed at front panel)	Measured Weight/(g) (using standard balance)	Percentage Error/(%)	Indicated Weight/(g) (displayed at front panel)	Measured Weight/(g) (using standard balance)	Percentage Error/(%)
1	600		605	0.8			
2	800					810	1.3
3	1000		995	-0.5			
4	1200					1200	0.0
5	1400		1405	0.4			
6	1600					1590	-0.6
7	1800		1810	0.6			
8	2000					2005	0.3
9	2200		2190	-0.5			
10	2400					2400	0.0
11	2600		2610	0.4			
12	2800					2820	0.7
13	3000		2995	-0.2			
14	3200					3185	-0.5
15	3400		3405	0.1			
16	3600					3610	0.3
17	3800		3810	0.3			
18	4000					4005	0.1

Table 4.1 Test Results

5.0. CONCLUSION

According to the test results it can be seen that there are some deviations with the required weight and the actual weight but as a percentage error it is not significant in most cases except one. Therefore the main purpose of the task, which is to measure the required chemical weights precisely without human interferences, is succeeded. Also the other objectives were also achieved from this machine. Mixing of each chemical in a specified time was also accurate enough for the purpose and well controlled by the PLC program. The front panel (touch screen) fulfills the easy operation of the machine and also it has been programmed for three access levels and protected by two different passwords, and hence the secrecy of formulation is also secured. Furthermore there is a flexibility of programming the touch panel for future requirements and development works such as displaying error messages and alarming machine faults. Also the machine can be further developed for measuring and displaying the important properties (such as viscosity and PH value) of the ultimate compound by adding suitable sensors and interface with the compatible PLC module.

6.0. REFERENCES

[1] Tapas Raj, Ashirvad Jena, "Design and Development of an automated Paint Mixing Machine", Bachelor of Technology, National Institute of Technology, India, 2014.

[2] Mohamed A. Muftah, Abdulgani M. Albagul, Abdullah M. Faraj. "Automatic paint mixing process using lab view", *Mathematics and Computers in Science and Industry*, vol.31, pp 233-238, Oct. 2014.

[3] Raphael M. Asuncion, Ryan D. Prodigalidad,Danuel V. Ramirez, Luisito R. Tomelden, "An Automated Microcontroller-based Cocktail Mixer and Dispenser", *DLSU Engineering e-Journal*, Vol.1, pp. 111-125, March 2007.

[4] Choube Khyati Amol, Gole Priyanka Dilip, Khopade Aditi Shahaji, Prof. Anagha Kunte, Mr. Abhishek Dandekar, "Weight Based Liquid Filling Using PLC and HMI", *TECHNO-2K17 (Technical Symposium)*, pp 55-60.

[5] Riza Gurbuz, "Controlling Flow Rate and Fluid Level by Variable Frequency Drive Unit", *The Archive of Mechanical Engineering*, Vol. 57, pp 393-404, 2010.

[6] ABB. (2015, Nov., 26). *Methods of Fluid Level Measurement in Industrial Processes*,[On-line]. Available: https://www.azom.com/article.aspx?ArticleID=12457 [Jan 2016].

[7] V.B. Bhandari, "Shafts,Keys and Couplings", in *Design of Machine Elements*, Second edition, New Delhi, Tata McGraw-Hill Publishing Company Limited, 2007, pp 323-345.

[8] *Beam Design Formulas with Shear and Moment Diagrams*,(2005 Edition), [On-Line]. Available: http://www.awc.org/pdf/codes-standards/publications/design-aids/AWC-DA6-BeamFormulas-0710. [23 May 2015].

[9] "Weighing", Internet: https://www.aandd.jp/products/weighing/loadcell/lcb04.html, [April 10, 2014].

[10] "Miniature Solenoid Valves", Internet: http://www.takasago-fluidics.com/products/products_valve/ , [March. 11, 2014].

[11] "Recommended products", Internet: http://www.xinje.com/en/ProductIndex.asp , [June 18, 2014].

[12] "Products", Internet: http://www.rotofluidpumps.com/ftss.htm , [February 25, 2013].

[13] "Industrial Automat", Internet: http://www.deltaww.com/Products/CategoryListT1.aspx?CID=06&hl=en-US , [February 10, 2012].

[14] "mV transmitter", Internet: http://www.prelectronics.com/?altTemplate=showproduct&id=2481 , [April 28, 2016].