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by David Harries

FILE	7309_DAVID_HARRIES_1502997_174990_157680251.DOCX (5.28M)		
TIME SUBMITTED	13-DEC-2019 02:14PM (UTC+0000)	WORD COUNT	5783
SUBMISSION ID	116301790	CHARACTER COUNT	30652

Course: BSc (Hons) Electrical and Electronic Engineering
Module: SGEE6003 Major Project
Assignment: 1. Project Definition, Research, and Quality Planning
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University Number: 1502997
Date Submitted: 6th Dec 2019
Word Count: 3910

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1. Executive Summary

The project is based on the Finishing Station in the CIM system in G8. It is outdated and must be brought up to “Industry 4.0” standards, hence it requires a new Linear Drive System. To solve this problem, the existing system was analyzed, and three solutions were derived that were suitable for this project.

The first solution was to use a Siemens V90 drive and S-1FL6 servo motor system, the second was to use an ABB MicroFlex e190 drive and an e-Series servo motor, and the third was to use a Mitsubishi Melservo J4 system.

By using an FDS and a weighted scoring system, the three solutions were compared, which resulted in the Siemens solution to be the most suitable for the project. This was primarily due to its lower cost which stayed within the budget, and the compatibility with the existing system.

Going forward, the Siemens V90 drive and S-1FL6 servo motor will be used to develop the new linear drive system. The design process will begin shortly after the interim presentation and will consist of further background research into this solution, along with the TIA and V90 software packages. The FDS and management techniques shown in this assignment will also be used going forward to ensure the project’s success.

2. Introduction

The aims and objectives of this project are to upgrade the outdated Finishing System with a new linear drive system. The existing system has poor speed and position control while also having two-speed modes available. The HMI screens are also outdated and lacking functionality which prevents the system from being used as a useful educational tool.

Therefore, by upgrading the linear drive system, better performance from the finishing robot can be achieved while also improving the HMI screens to make the system a more useful educational tool, as more data can be provided to the user.



Figure 3.3 - Existing Panel

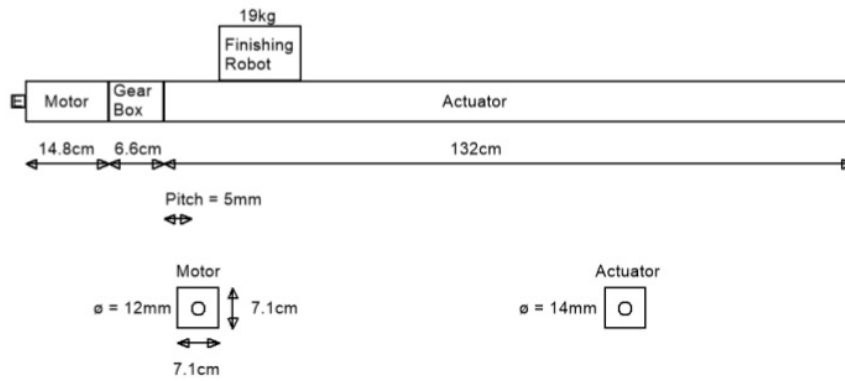


Figure 3.4 - Existing System Construction Diagram

The pitch of one rotation of the shaft moves the robotic arm 5mm linearly. Therefore, the motor must complete 264 rotations to move the full 132cm. The motor can move the finishing robot from end to end within 31 seconds giving the system a linear velocity of 43mm/s. The maximum current draw for the system is when the motor is rotating at 500 rpm. This gives an I_{max} of 4A and V_{max} of 30V.

$$\therefore P_e = I_{max} \times V_{max} = 4 \times 30 = 120W$$

$$\text{Assuming } \% \eta = 0.8$$

$$P_m = 120 \times 0.8 = 96W$$

$$\omega_m = rpm \times \frac{2\pi}{60} = 500 \times \frac{2\pi}{60} = 52.359 rad/s$$

$$T = \frac{P_m}{\omega_m} = \frac{96}{52.359} = 1.834 Nm$$

Therefore, the required torque to move the load at 43mm/s is 1.834Nm. The existing motor uses a planetary gearbox to lower the RPM of the actuator shaft meaning there may be a limiting mechanical factor to take into consideration when replacing the motor for a more powerful one.

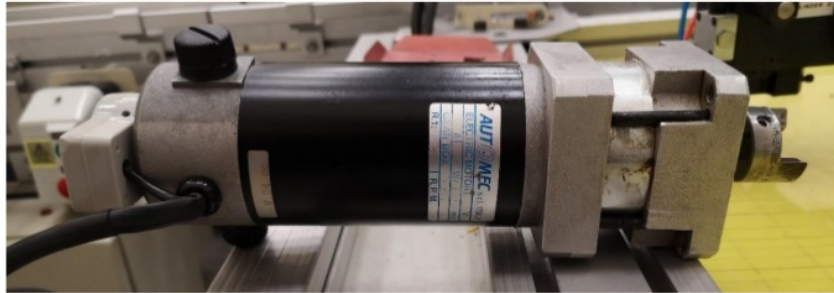


Figure 3.5 - Existing DC Motor

The existing motor in **Figure 3.5** has a shaft diameter of 12mm and uses a coupling to connect to the shaft of the actuator which has a diameter of 14mm. The motor and gearbox lengths are 148mm and 66mm respectively, giving a combined length of 214mm. The combined volume of the motor and gearbox is roughly 1078.78cm^3 . The motor is mounted to the actuator using 4 screws. The positions of these screws are in equidistant positions 45mm from the shaft in each corner of the gearbox as shown in **Figures 3.6** and **3.7**.



Figure 3.6 - Motor Mounting Screw Holes

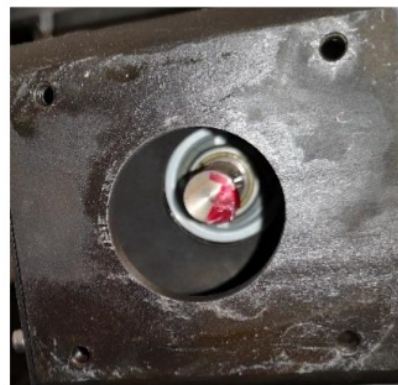


Figure 3.7 – Actuator Mounting Screw Holes

Additionally, the existing HMI screens for the finishing station have very few functions.

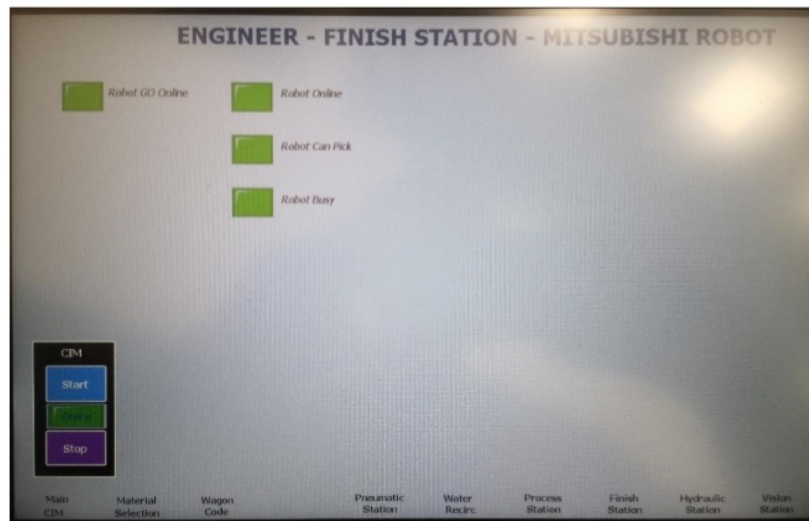


Figure 3.8 - Finishing Station HMI Screen

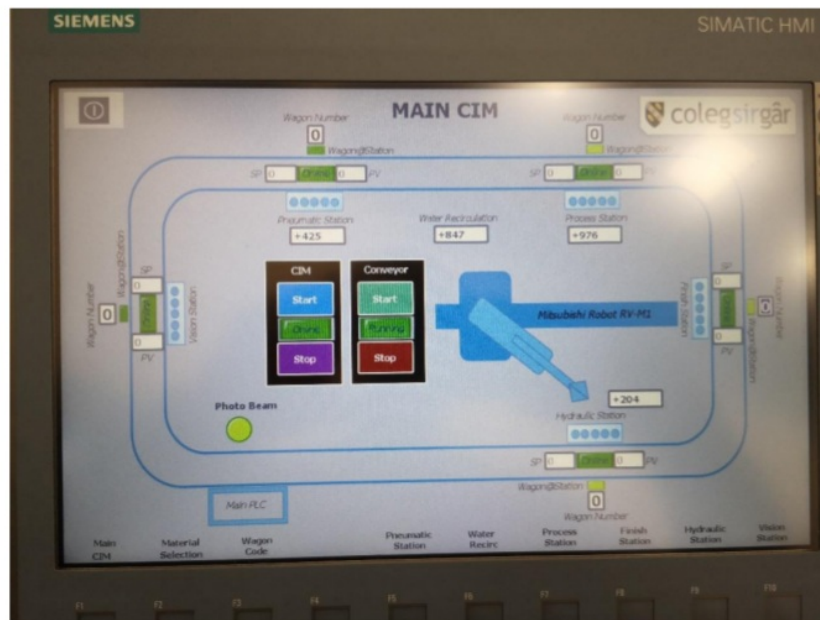


Figure 3.9 - Main CIM Screen

As **Figure 3.8** shows, the screen could be upgraded to have more functionality such as control modes, and diagnostics. In the Main CIM Screen, there is a static diagram of the finishing robot which currently serves no purpose. Therefore, in addition to replacing the drive system for the finishing robot, HMI upgrades must be made.

Once upgraded, the system should provide a useful educational tool for teaching motor operation for engineering students from levels 3, through 6. The relevant modules would include; PLC programming, motor operation, instrumentation and control, and motor and generator characteristics and performance.

3.2 – Ethical Engineering

Engineering has a direct impact on society and the quality of life of billions. Therefore, it is paramount that engineers provide honest, fair, impartial and ethical services in the interest of preserving the health, safety, and welfare of the general public. The Royal Academy of Engineering and the Engineering Council state that the fundamental ethical principles are:

1. “Honest and Integrity:

Engineering professionals have a duty to uphold the highest standards of professional conduct including openness, fairness, honesty, and integrity.

2. Respect for Life, Law, the Environment and Public:

Engineering professionals have a duty to obey all applicable laws and regulations and give due weight to facts, published standards and guidance and the wider public interest.

3. Accuracy and Rigour:

Engineering professionals have a duty to acquire and use wisely the understanding, knowledge, and skills needed to perform their roles.

4. Leadership and Communication:

Engineering professionals have a duty to abide by and promote high standards of leadership and communication.”

(Royal Academy of Engineering, Engineering Council, 2017)

These principles will be adhered to during all stages of this project by taking responsibility for the success or failure of the project, doing background research to acquire the knowledge and skills required to complete the project, work to all relevant health and safety standards, and to mitigate negative impacts to the environment.

3.3 – Environment and Sustainability

The existing system will be replaced with a more efficient system that has four quadrant capabilities. By having 4 quadrant operation, regenerative braking can be achieved allowing energy to be generated and pumped back into the supply when the motor is braking in either direction. Furthermore, by having a more efficient motor, less electrical power is wasted allowing for more to be converted into mechanical power to drive the actuator.

Replacing the existing system with a drive that is up to “Industry 4.0” standard will allow for network communications using a communications protocol such as PROFINET. This will allow for profiles such as PROFINergy to be used which allows the power consumption of automated systems to be managed over a PROFINET network without the need for hardwired systems. Examples of when the use of PROFINergy would reduce power consumption would be:

- Brief Pauses (< 1 hour) enables devices to be routinely switched off.
- Long Pauses (Hours or Days) devices can be switched off completely or put into deeper ‘sleep’ modes.
- Unscheduled Pauses (Breakdowns) it will initially put the device into a stop condition if a breakdown is detected.
- Measuring and visualization of the load; Data is collected by instrumentation and known electrical parameters. By analyzing trends in energy requirements and consumption, more efficient/effective methods of energy conservation can be used.

(PI, 2010)

Any hardware used must be made of a high percentage of recyclable materials so that when the system is no longer up to modern standards, the materials can be repurposed without harming the environment.

3.4 – Health and Safety

Due to this project involving a robot integrated into a CIM system, health and safety regulations regarding robots must be considered. ISO 10218 Robots and robotic devices – Safety requirements for industrial robots (2011) – Part 1 and 2 state that “requirements and guidelines for the inherent safe design, protective measures, and information for use of industrial robots. It describes basic hazards associated with robots and provides requirements to eliminate, or adequately reduce, the risks associated with these hazards.”

ISO 10218 - Part 1 general requirements state that collaborative robotic operation shall provide a visual when the robot is in collaborative operation and must comply with one of the following:

- 5.10.2 Safety-rated monitored stop (IEC 60204-1 category 2)
- 5.10.3 Hand guiding (requires emergency stop and enabling device)
- 5.10.4 Speed and separation monitoring
- 5.10.5 Power and force limiting by inherent design or control

5.10.2 states how a robot should operate in the presence of an operator or an obstruction. This could be implemented by building a light curtain that stops the system when the obstruction crosses a boundary and resumes when the obstruction clears. However, all of the standards could be implemented to increase the safety of the system.

The HASAW act 1974 states mandatory risk assessments must be taken on all new equipment. Therefore, a risk assessment will be carried out upon all new hardware that will be used within the project. Since the product will be an educational tool, the risk assessment will include training, testing, supervision, and access to both the hardware and the software elements of the system. (Health and Safety Executive, 1974)

Since the project involves 200+V AC, a secure panel must be constructed to fulfill the Provision and Use of Work Equipment Regulations 1998. The panel must have an interlock guard and a safety lock isolator along with a transparent window to see the panel’s interior without needing to open it. This will allow the panel to be safely used as an education tool.

3.5 – Risk and Liability

Risks that are a threat to the success of this project are mostly minimal. The primary risk is being uncertain on how much torque the shaft of the actuator can withstand without being under

too much stress. Control measures will be used to ensure that the shaft doesn't get damaged by limiting the torque exerted by the motor. Appropriate parameters will be set while under supervision based on a risk assessment. With these limitations and control measures put in place to safeguard the user, and machinery, the risk of damage to either will be greatly reduced. Lesser risks can be seen in the *Section 6*.

3.6 – Engineering Management Techniques

Project management and planning will be used throughout the project to ensure everything is done on schedule while meeting expectations. Examples of these techniques are using a Work Breakdown Structure, Gantt Chart, and Risk Assessment.

3.7 – Intellectual Property

All IP from this project belongs to Coleg Sir Gar.

4. Function Design Specification and Test Plan

4.1 – Function Design Specification

The Finishing Robot is controlled using an obsolete Keyence PLC and an incremental encoder connected to the motor for position feedback. This system is slow, outdated, lacks diagnostic facilities and has poor positioning and speed control.

The dynamic performance of the new system must be at least equal to that of the existing system. Therefore, it must meet these criteria as minimum requirements:

- Move a load of 19kg with a maximum torque of 1.834Nm @ 500rpm.
- Move the entire length of the actuator (132cm) within 31 seconds, giving the robot a minimum linear velocity of 43mm/s.
- Position control so that the position of the robot is always fed back to the controller allowing manual, and automatic position control.
- Speed control so that the robot can move at a range of speeds, rather than two. These speeds must be able to be manually or automatically adjusted within limits.
- The robot ideally will match the speed of the conveyor and follow the location of wagons so that it can pick up and place products on and off the wagons as they move. The conveyor moves at 176mm/s meaning that the motor must run at 2200rpm.
- Motor Efficiency must be ($\eta > 0.8$).
- Must be interfaced with the existing PROFINET network.
- Must have four-quadrant operation and regenerative braking.

In addition to these physical parameters, the project requires new HMI screens that include:

- An animated mimic of the linear drive system which shows the current position of the finishing robot on the HMI screen as it moves, in real-time.
- Diagnostic tools to monitor the system. This screen must display data obtained through the PROFINET network from the motor. This must include a graph that updates in real-time showing the linear velocity of the actuator.
- An HMI screen that can enable automatic control from the Mitsubishi Robot, and manual control with the ability to move the robot back and forth using the HMI as a controller.

- Safe stopping is required in the form of a physical emergency stop switch, and an HMI stop button.

A new panel must be built to replace the existing system which will house safety features, a PLC, a Drive, and enough trunking. This panel will be stationed on the opposite side from the existing system's panel and will have dimensions of 500mm x 800mm x 250mm. To ensure futureproofing of the system, the enclosure will be made larger than needed so that further development can take place. The panel door will be transparent allowing to view its contents while keeping the door locked shut.

By developing this system, sustainability is promoted as using an AC motor instead of a DC motor increases efficiency. A more efficient method of speed control will be used which reduces energy loss through heat from the resistors, and the data from the motor will be shared across a PROFINET network allowing for improvements to be made much easier to allow for the efficiency to be further increased and to meet the requirements of "Industry 4.0".

The operational conditions for this system will be indoors in the G8 lab. It will not need to withstand harsh conditions as it will be housed within a controlled environment.

This project must be done within the budget of £1100 and has will be fully designed, built and tested by April 24th, 2020.

4.2 – Test Plan

Iteration 1 - Hardware Tests				Date:
Test no.	Description	Expected Value	Actual Value	Pass / Fail / Comment
1	Torque	$\geq 1.834\text{Nm}$ @ 500rpm.		
2	Minimum velocity	$\geq 43\text{mm/s}$.		
3	Conveyor velocity	$= 175\text{mm/s}$ @ 2200rpm.		
4	Motor efficiency	$\geq 0.8\eta$.		
5	Finishing Robot can move with varying speed	Zero to Maximum Velocity.		
6	Panel	Houses all system components and trunking with room for future expansion.		
7	Four quadrant operation.	Regenerative Braking in both directions		
8	Communication with PROFINET network.	N/A		
9	Emergency stop	Physical button cuts power to the system instantly.		

Iteration 1 - Software Tests				Date:
Test no.	Description	Expected Value	Actual Value	Pass / Fail / Comment
1	Speed control from HMI	Screen with manual and automatic modes.		
2	Position control from HMI	Screen with manual and automatic modes.		
3	Mimic animation in HMI screen	Position of finishing robot updating in real-time.		
4	Diagnostic HMI screen	Displays data in real-time.		
5	The home screen has an overview of the system and can be used to navigate HMI screens.	Navigation between screens and displays system overview.		
6	Tabs at the bottom of each HMI can be used to access other screens.	Navigation between screens using tabs		
7	Safety features.	Emergency stop buttons on the HMI screens stop the system		

5. Literature Review

A common solution to linear drives in industry is using Servo motors. Servo motors differentiate from other motor types regarding the motor data provided on a rating plate. Typically, servos are characterized by the rated torque, rather than power. Servos torque can, however, exceed their rated torque by 5-10 magnitudes for short bursts. This makes them very useful for non-continuous applications. Servos also often come with an integrated encoder which is inaccessible from the exterior. Therefore, the resolution of the encoder is also often stated on the rating plate.

(Jens Weidauer, 2014)

Figure 5.1 shows a typical position control diagram for a Servo motor.

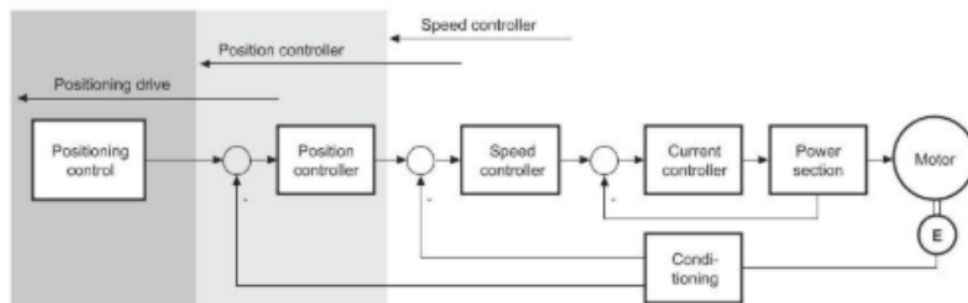


Figure 5.1 - Position Control Diagram (Jens Weidauer, 2014)

Due to the integrated encoder, servos are specialized for high-response, high-precision positioning applications such as linear drives, elevators, robotics, and high precision manufacturing processes. Therefore, they are an ideal solution for this project as the aim is to have high precision position control, improved speed range, and enough torque to move the load at these speeds.

The existing system uses 1.83Nm @ 500rpm, to produce a linear velocity of 43mm/s. Therefore, a motor that provides a higher torque at a higher rpm is required. One of the desirable criteria of the FDS is for the linear drive to match the velocity of the conveyor of the CIM system.

$$\frac{\text{Conveyor Speed}}{\text{Pitch}} = \frac{175\text{mm/s}}{5\text{mm}} = 35 \text{ rotations per second}$$

$$35 \times 60 = 2113\text{rpm} = 220\text{rad/s}$$

$$\frac{400}{220} = 1.81\text{Nm}$$

$$\frac{2113\text{rpm}}{500\text{rpm}} \times 1.81\text{Nm} = 7.65\text{Nm}$$

Therefore, a servo that has the capability of providing 7.65Nm is required to match the conveyor speed. However, this does not account for the friction of the system which may increase the torque requirement. A friction coefficient of the existing system is calculated below;

$$B = \frac{T}{W} = \frac{1.83}{52} = 0.0346$$

	Servo drive with				
	DC motor	brushless DC motor	synchronous motor	asynchronous motor	stepper motor
typical power range	up to 20 Nm	up to 200 Nm	up to 200 Nm	up to 2,000 Nm	up to 5 Nm
dynamic	high				medium, acceleration is limited (stepping losses)
torque	constant over the entire speed range				drops off significantly at higher speeds
control	simple	more complex	complex		simple, open-loop controlled
motor encoder	tacho-generator	commutation encoder	resolver, sine/cosine encoder	incremental encoder	not required
actuator	simple, due to mechanical commutation	complex, due to electronic commutation			simple
manual tuning	necessary (by the user)	not necessary (performed by the controller)			not necessary
device size	small			larger	small
losses, temperature rise of the motor	low			higher, due to additionally required magnetisation current	higher, due to constant current flow

Figure 5.2 - Servo Drive Overview (Jens Weidauer, 2014)

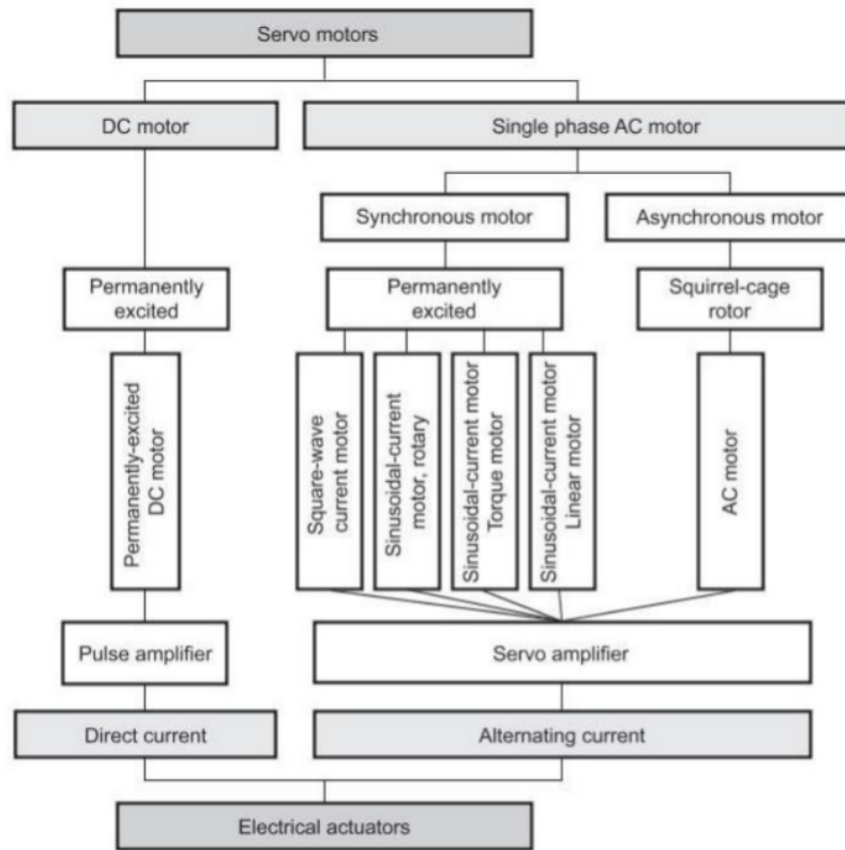


Figure 5.3 - Classification of Servo Drives by Motor and Controller (Jens Weidauer, 2014)

Using **Figures 5.2** and **5.3**, an ideal servo motor type for this project is a single-phase AC, synchronous motor because they have small frames, have low-temperature losses, and a constant torque over the entire speed range. The only alteration to the common setup seen in **5.2** is the encoder type. An ideal encoder type for this project is an incremental encoder as it provides the position data via a counter signal in a series of pulses allowing for simple position and speed control.

To stay within the budget, avoiding unnecessary costs is crucial. Therefore, the dimensions of the motor should be within a +10% limit so that no extra support is required. Additionally, peripherals such as enclosure, circuit breakers, trunking and cabling will be required. Therefore £200 will be set aside from the budget to purchase these. This leaves a £900 budget for a motor, drive, cables, and PLC.

5.1 – Solution 1 – Siemens SIMOTICS S-1FL6 Motor and V90 Drive

The first solution for developing this project is to use a Siemens system that would integrate into the existing PROFINET network. The system consists of a SINAMICS V90 servo converter and the SIMOTICS S-1FL6 servo motor. A block diagram of how this system could be set up using PROFINET can be seen in **Figure 5.4**.

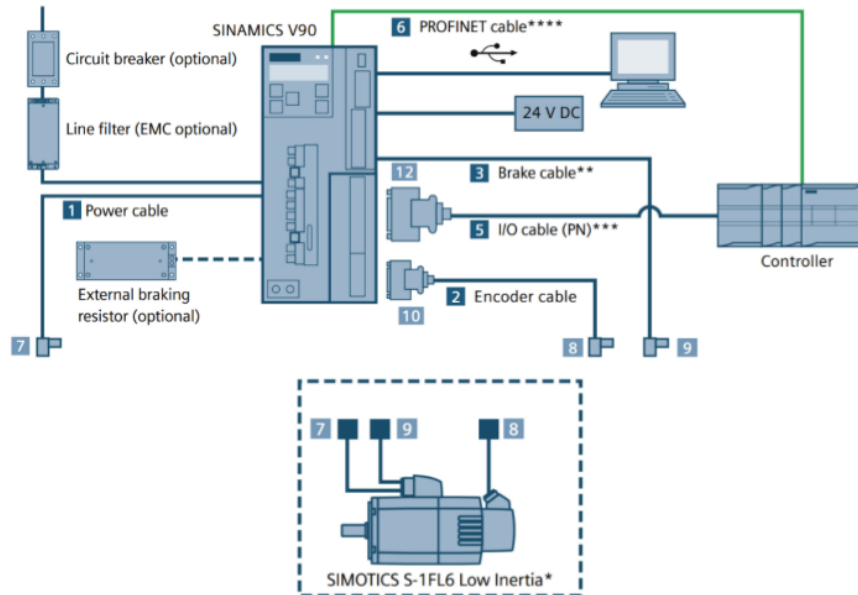


Figure 5.4 - SINAMICS V90 System Connection Diagram (SIEMENS, 2016)

An ideal model from this line of motors is the 1FL60422AF211AA1 0.75kW, 3000RPM, 230VAC, 2.39Nm. **Figure 5.5** shows the torque characteristics.

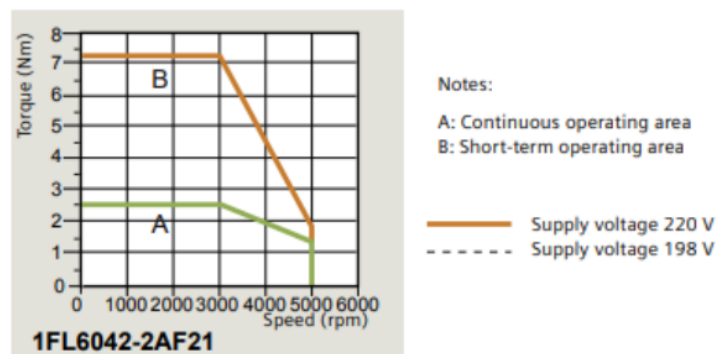
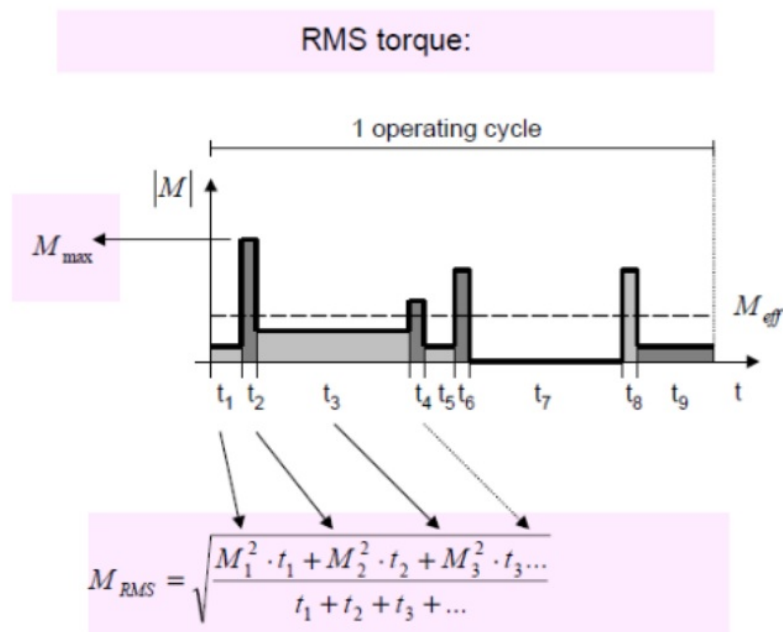


Figure 5.5 - 1FL60422AF211AA1 Torque Curve (SIEMENS, 2016)

The torque of the motor is constant throughout the 0-3000rpm range. When under short-term operation the motor can operate with up to 7.2Nm. This torque can be achieved if it is in short bursts to allow for the motor to cool.

SIEMENS



The RMS value is calculated by extracting the square root. Contrary to generating the arithmetic average, the higher torques are more heavily weighted due to the power of 2. This is required, as the power loss P_V in the motor increases to the square of the current:

$$P_V = U \cdot I \xrightarrow{\text{with } U = R \cdot I \text{ and } R = \text{const.}} P_V \sim I^2$$

Figure 5.6 - RMS Torque Equation (SIEMENS, 2016)

Figure 5.6 shows that periods where the torque is increased past its rated torque, power loss also increases. This is due to an increase in current which creates a temperature increase in the

stator. Since the robot will not be in continuous use for extended periods, this overheating will not be an issue.

The servo drive model selected to control the motor is the 6SL32105FB108UF0. It operates on a 230VAC supply and can provide the 0.75kW to the motor. It is fully interfaceable with PROFINET allowing for both speed and position control modes.

CYFEIRNOD REFERENCE	DISGRIFIAD DESCRIPTION	PRIS UNIGOL UNIT PRICE £	UNEDAU UNIT	PRIS CYFAN TOTAL PRICE £
6FX30022CT201AD0	V90 SIGNAL CABLE PRE-ASSEMBLED 3M	51.67	1	51.67
6FX30025CK011AD0	V90 POWER CABLE PRE-ASSEMBLED 3M	34.83	1	34.83
1FL60422AF211AA1	V90 SERVOMOTOR 2.39NM 3000RPM 230VAC	269.78	1	269.78
6SL32105FB108UF0	V90 SERVO DRIVE 0.75KW 230V 1/3PH PN	479.32	1	479.32
				835.60

(Parmley Graham 2019, Personal Communication, Nov)

5.1.1 – Advantages

Most of the hardware within the CIM system is already manufactured by Siemens. Therefore, there will be no compatibility issues when integrating this system onto the existing network. Additionally, the software package TIA portal is readily accessible from college computers and is familiar, which will reduce the time required to learn new software.

Finally, there is no need to buy a new PLC to control the system as there is a SIEMENS 1212C PLC available to be used and implemented into this system. Therefore, the price of this solution is drastically cut. The prices were obtained via a quote from Parmley Graham with a 15% discount. With the total being £835.60, this leaves at least £200 for the remaining components.

5.1.2 – Disadvantages

The existing finishing robot is manufactured by Mitsubishi and would, therefore, be less compatible with this solution.

5.2 – Solution 2 – ABB e-Series Servo Motor and MicroFlex e190 Drive

The second solution to the project would be an ABB system. ABB uses an ethernet protocol called EtherCAT which can interface with PROFINET, thus using an ABB system will still allow for integration to the existing PROFINET network.

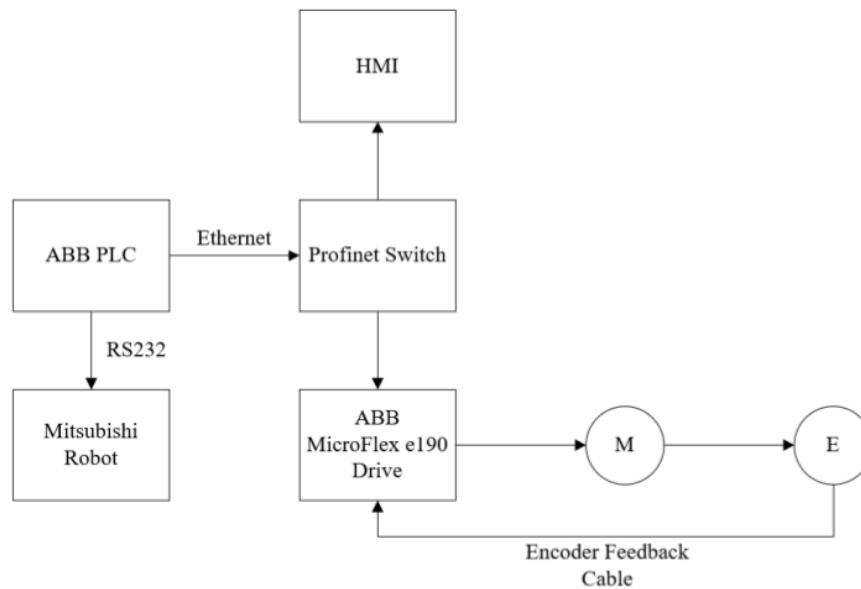


Figure 5.7 - ABB System Block Diagram

The ESM08X-751-302-T1N0A00 0.75kW, 3000rpm, 220VAC, 2.39Nm motor from the e-Series line is an ideal model for the project. **Figure 5.8** shows the torque motor's characteristics.

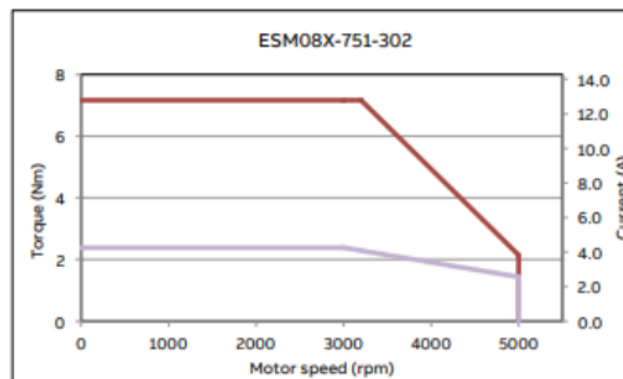


Figure 5.8 - ESM08X-751-302-T1N0A00 Torque Characteristics (ABB Automation, 2019)

The torque characteristics of this motor are almost identical to that of the Siemens. The peak torque is 7.16Nm and the continuous stall torque is 2.39Nm, both remaining constant through the 0-3000rpm range.

The servo drive model selected to control the motor is the MFE190-04UN-06A0-2. It operates on a 230VAC supply and can provide 0.75kW to the motor. It is interfaceable with PROFINET allowing for both speed and position control modes.

5.2.1 – Advantages

The MicroFlex and e-Series servo motors are relatively new releases from ABB and therefore are up to industry 4.0 standard and will be future proof for a long time.

If the finishing robot itself were to be replaced with an ABB robot, this solution would already be compatible with it further futureproofing the systems development.

5.2.2 – Disadvantages

The cost of this system is £1214.40 which is above the budget. In addition to this cost, an ABB PLC will be required to compatibly control the drive which would further increase the cost.

Most of the existing system uses Siemens hardware and therefore compatibility issues may become a problem with this solution.

5.3 – Solution 3 – Mitsubishi Melservo J4 Servo Motor and Drive

The final solution is to use a Mitsubishi system. The most advanced servo system by Mitsubishi is the Melservo J5 series. The J5 line is capable of communications over ethernet protocols such as CC-linkIE TSN and PROFINET. However, this line of products is not available in the UK until the 2nd quarter of 2020.

The Melservo J4 series is the next line of servo drives and motors down from the J5, so this will be considered instead. Unfortunately, this series does not use ethernet communications to control the drive and instead uses SSCNET III/H. However, the speed of the motor can be directly controlled by PWM.

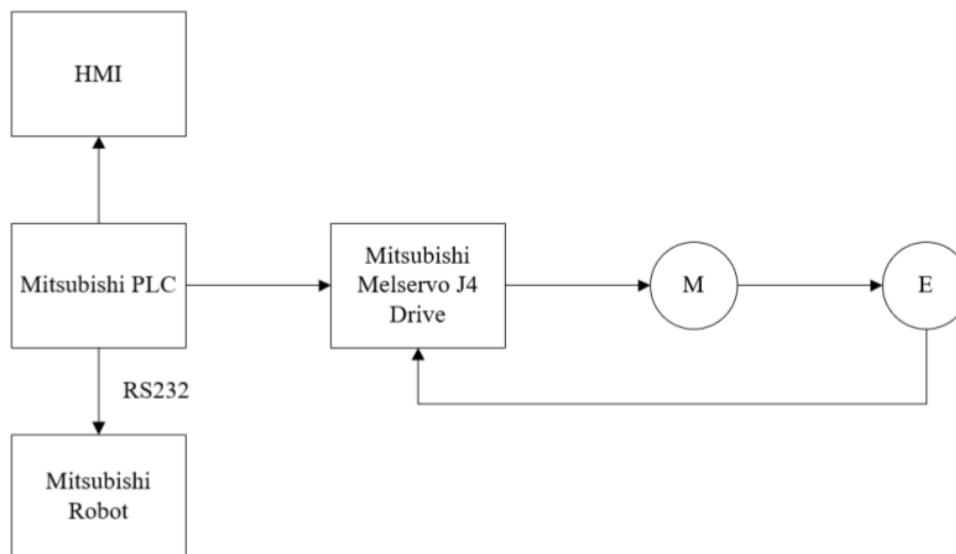


Figure 5.9 - Mitsubishi System Block Diagram

An ideal servo from the J4 series is the HG-MR-73B. **Figure 5.10** shows the torque characteristics of this motor.

HG-MR73(B) (Note 1, 2)

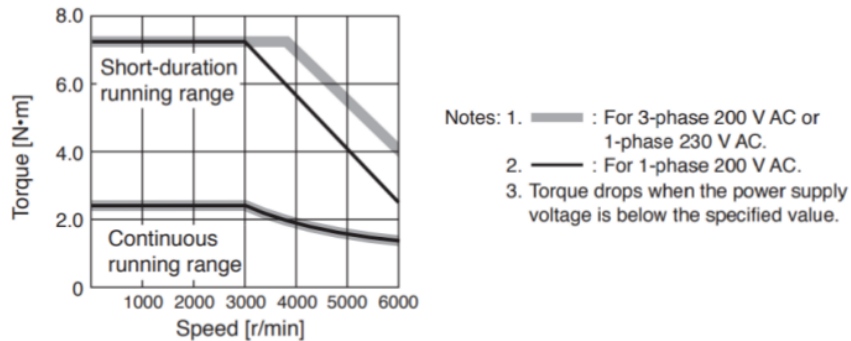


Figure 5.10 - HG-MR-73B Torque Characteristics (Mitsubishi Electric, 2012)

The torque characteristics show that for a short duration the motor can run at a peak torque of 7.2Nm and a continuous torque of 2.4Nm, both from 0-3000rpm.

The drive model that would be used to drive the motor is the MR-J4-70B-RJ. It can provide 750W to the motor while operating on 200VAC to 240VAC.

5.3.1 – Advantages

The existing finishing robot in the CIM system is manufactured by Mitsubishi and therefore using a Mitsubishi motor and drive will be compatible with the existing system.

5.3.2 – Disadvantages

The cost of this system is £1651.50 and is way over the projects budget. This cost also doesn't consider the cost of an additional PLC that would be compatible with this system, which would further increase the cost.

The J4 series cannot communicate over ethernet and therefore cannot be fully integrated into the existing PROFINET network which is a requirement of the FDS.

5.4 – Solution Comparison and Selection

To select the most ideal solution to this system, a scoring system will be used to rank each solution, where important features from the FDS hold a higher weighting. The solution with the highest score will be the one that is most suitable for this project and will be used henceforth.

Motor Comparison			
Ideal	Solution 1 - Siemens	Solution 2 - ABB	Solution 3 - Mitsubishi
Peak Torque (Nm)	7.2	7.16	7.2
7.65Nm	5	4	5
Rated Torque (Nm)	2.39	2.39	2.4
> 1.82Nm	1	1	1
Rated Speed (rpm)	3000	3000	3000
> 2200rpm	1	1	1
Max Speed (rpm)	5000	5000	6000
N/A	1	1	2
Power Rating (W)	750	750	750
750	1	1	1
Regenerative Braking	Yes	Yes	Yes
Yes	5	5	5
Encoder Type + Resolution	Incremental Encoder 2500 ppr	Absolute Encoder 17bit/rev	Incremental Encoder 4194304 ppr
Incremental	5	1	10
Inertia (10–4kg·m ²)	0.897	0.9	0.586
N/A	1	1	2

Weight (kg)	2.8	2.4	2.8
< 3kg	3	5	3
Dimensions $L \times W \times H$ (cm^3)	$13.9 \times 8.0 \times 8.0$ 889.6	$12.2 \times 8.0 \times 8.0$ 780.8	$11.2 \times 8.0 \times 8.0$ 716.8
< 1078.78 cm^3	1	3	5
Mounting Hole Location (mm)	45	45	45
45mm	1	1	1
Shaft Diameter (mm)	19	19	19
14	1	1	1
Total	26	25	37

Drive Comparison			
Ideal	Solution 1 - Siemens	Solution 2 - ABB	Solution 3 - Mitsubishi
Ethernet Communications	Yes	Yes	No
Yes	10	10	0
Dimensions $W \times H \times D$ (cm^3)	$8.0 \times 17.0 \times 19.5$ 2652	$7.0 \times 21.5 \times 20$ 3010	$6.0 \times 16.8 \times 26.5$ 2671
D < 25cm	10	5	1
Safety Features	Yes	Yes	Yes
Safe Torque off	10	10	10
Total	30	25	11

Additional Comparisons			
Ideal	Solution 1 - Siemens	Solution 2 - ABB	Solution 3 - Mitsubishi
Compatible with Existing	Yes	No	Partially

Systems and Software			
Yes	10	0	5
Cost	£835.60	£1214.40	£1651.50
< £1100	10	0	0
New PLC Required	No	Yes	Yes
No	10	0	0
Total	30	0	5

Cumulative Points			
	Solution 1 - Siemens	Solution 2 - ABB	Solution 3 - Mitsubishi
Total	86	50	53

Table data obtained from manufacturer datasheets (ABB Automation, 2019), (Mitsubishi Electric, 2012), (SIEMENS, 2016).

By using this scoring system, it can be concluded that the Siemens system is the most suitable solution for the project. The biggest downfalls for the other two solutions were the budget, need for a new PLC, and incompatibility with the existing system.

Therefore, the system of choice going forward will be the Siemens V90 drive and S-1FL6 servo motor.

6. Project Planning, Work Breakdown, and Management Techniques

To maintain a steady workflow throughout the project and hit deadlines with quality work done, many management techniques have been employed. By making weekly logbook entries, a constant flow of work has been ensured as picking up from where the project was left off is made simple. Furthermore, each logbook details the work that needs to be done within the coming week, which again ensures that progress is being made.

A work breakdown structure has also been constructed so that it can give direction and objectives to work towards when unsure. It also ensures that all aspects of the project are progressed, and none are forgotten. The WBS is used in conjunction with a Gantt chart which is used to keep a work schedule.

A costing spreadsheet has been made for the current expenditure of the project, which will be updated as more is spent to ensure the budget isn't exceeded.

Table 1 - Costings Spreadsheet

6FX30022CT201AD0	V90 SIGNAL CABLE PRE-ASSEMBLED 3M	51.67	1	51.67
6FX30025CK011AD0	V90 POWER CABLE PRE-ASSEMBLED 3M	34.83	1	34.83
1FL60422AF211AA1	V90 SERVOMOTOR 2.39NM 3000RPM 230VAC	269.78	1	269.78
6SL32105FB108UF0	V90 SERVO DRIVE 0.75KW 230V 1/3PH PN	479.32	1	479.32
	Panel, Circuit Breakers, Trunking, Cabling	200	1	200
			Total	1035.6
			Remaining	64.4

Finally, a risk matrix has been made which details the potential risks that may occur during the project which could jeopardize its success.

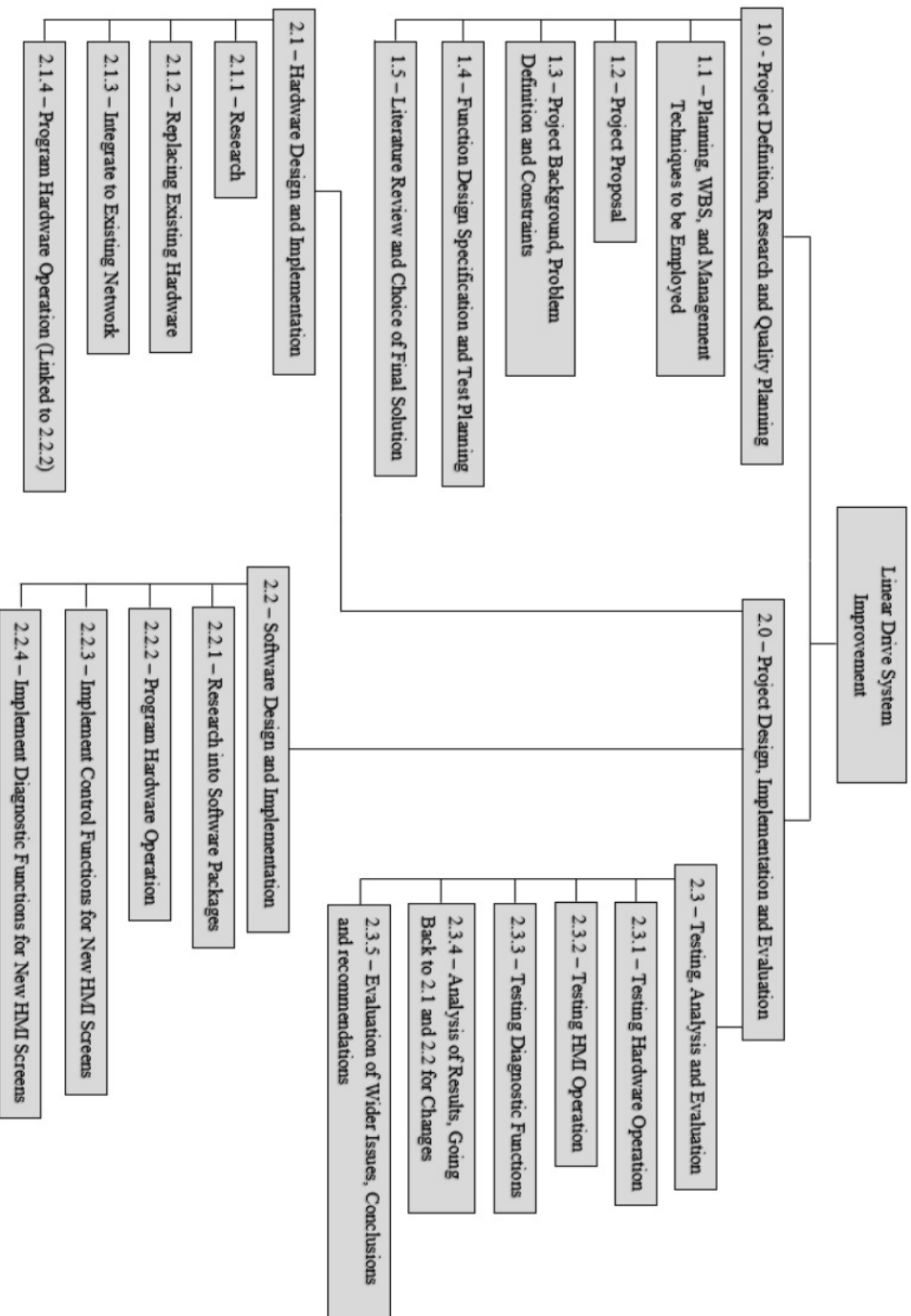


Figure 6.1 - Work Breakdown Structure

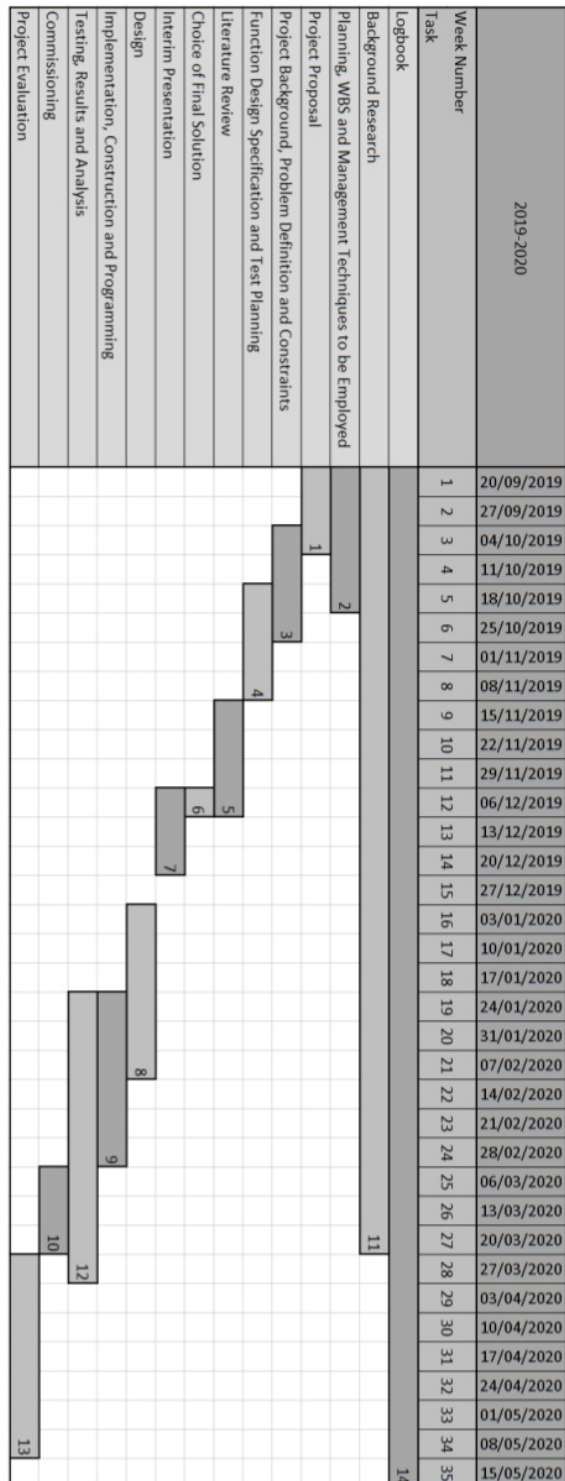


Figure 6.2 - Gantt Chart

	Minor	Moderate	Major	Critical
76-100%				
51-75%				
26-50%	Software Issues			
0-25%	Delay on Delivery of Order			Physical Damage to Components

Table 2

(Kendrick, 2015)

Delay on Delivery of Order – Could potentially push back progress on the design stage of the project. This is a minor risk to the project as the components are guaranteed to arrive.

Software Issues – This includes the learning process, finding resources to use, bugs and college computer issues. This is a minor risk and will not cause project failure.

Physical Damage to Components – If components are damaged in transit, or any phase of the project then the project could fail. This is an unlikely scenario but must be considered.

7. Conclusions and Recommendations

At this stage of the project, everything has started to take shape. The work has been done to schedule according to the Gantt chart, which shows that the next stage of the project is to start the design process. The most suitable solution has been selected and parts have been ordered so that this phase of the project can begin.

An avid understanding of the problem at hand has been achieved and knowledge on the relevant subjects has been obtained, setting a solid foundation to continue the rest of the project with success.

All the named health and safety, ethical and environmental standards will continue to be a center point of the project to ensure that all procedures are done safely and correctly while improving the efficiency of the system.

With this report's completion, background research should now shift towards more specific subjects such as the V90 software, TIA portal and finding resources to use with the S-1FL6 motor to fulfill the FDS. This should continue throughout the design process to ensure that the final product is as well designed as possible.

The risks stated within the risk matrix must still be considered through the remainder of the project's lifespan, and if any other risks were to arise then the matrix must be updated so that the project is completed successfully. Likewise, if any of the risks do cause problems, the Gantt chart must be updated to reflect that, so that the remaining time can be reorganized to increase productivity.

In improvement that could be made to the project is to consider more than three possible solutions, as there are many more manufacturers that may provide a more suitable solution for the system. Furthermore, other solutions that involve designing a H-bridge circuit or driving the motor directly with PWM could be considered.

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Appendix

Electrical and Power

Standard	Year	Description
BS EN 61439 (many parts)	2009 - 2012	Low-voltage switchgear and controlgear assemblies
BS 5266 Parts 1 to 10 also BS EN 50172	1999 - 2008	Code of practice for emergency lighting
BS 5424 Parts 2 and 3, also IEC 60158 part 3	1985 - 1988	Specification for low voltage control gear
BS EN 60422	2008	Monitoring and maintenance guide for mineral insulating oils in electrical equipment
BS 5839 Parts 1 - 11, also PD6531:2010	1988 - 2010	Fire detection & alarm systems for buildings
BS EN 60079-30-2	2007	Electric surface heating
BS 6423	1983	Code of practice for maintenance of electrical switchgear and controlgear for voltages up to and including 1 kV
BS 6626	2010	Code of practice for maintenance of electrical switchgear and controlgear for voltages above 1 kV and up to and including 36 kV
BS EN 62305, 4 parts	2006- 2011	Code of practice for protection of structures against lightning
BS 7375	2010	Code of practice for distribution of electricity on construction and building sites
BS 7430	1998	Code of practice for earthing
BS 7671	2008 - 2011	Requirements for electrical installations. IEE Wiring Regulations. Seventeenth edition
BS 7909	2008 - 2011	Code of practice for temporary electrical systems for entertainment and related purposes.
BS EN 50110 Parts 1 and 2	2004 - 2010	Operation of electrical installations
IEC 60479 Parts 1-4, also PD6519	1994- 2005	Guide to effects of current on human beings and livestock.
BS EN 60529	1992	Specification for degrees of protection provided by enclosures (IP code)
BS EN 60947 Parts 1-8	2001 - 2011	Specification for low voltage switch gear and control gear

Appendix 1 - Electrical and Power Regulations (Health and Safety Executive, 2018)

Electrical Appliances

Standard	Year	Description
BS 1362	1973	Specification for general purpose fuse links for domestic and similar purposes (primarily for use in plugs)
BS 1363 Parts 1 -5	1995 - 2008	13 A plugs, socket-outlets and adaptors.
BS EN (IEC) 60309, Parts 1,2, 4	1999 - 2007	Plugs, socket-outlets and couplers for industrial purposes.
BS EN 60320, Parts 1, 2	1999 - 2009	Appliance couplers for household and similar general purposes.
BS EN 60335, Many parts		Specification for safety of household and similar electrical appliances

Appendix 2 - Electrical Appliances Regulations (Health and Safety Executive, 2018)

Electromagnetic Compatibility

Standard	Year	Description
BS EN 61000-6-3,4	2007 - 2011	Electromagnetic compatibility. Generic emission standard.
BS EN 61000-6-1,2	2005 - 2007	Electromagnetic compatibility. Generic immunity standard.
BS EN (IEC) 60801, Part 2	1993	Electromagnetic compatibility for industrial-process measurement and control equipment. Electrostatic discharge requirements

Appendix 3 - Electromagnetic Compatibility Regulations (Health and Safety Executive, 2018)

Machinery

Standard	Year	Description
BS EN ISO 13850	2008	Safety of machinery. Emergency stop. Principles for design.
BS EN 953	1997 - 2009	Safety of machinery. Guards. General requirements for the design and construction of fixed and movable guards
BS EN 13849	2008	Safety of machinery. Safety related parts of control systems. General principles for design
BS EN 982	1996 -2008	Safety of machinery. Safety requirements for fluid power systems and their components. Hydraulics
BS EN 983	1996 -2008	Safety of machinery. Safety requirements for fluid power systems and their components. Pneumatics
BS EN 1037	1996 -2008	Safety of machinery. Prevention of unexpected start-up
BS EN ISO 12100	2010	Safety of machinery. General principles for design. Risk assessment and risk reduction.
BS EN 1088	2008	Safety of machinery. Interlocking devices associated with guards. Principles for design and selection.
PD 5304	2005	Safe use of machinery
BS EN 60204 many parts		Safety of machinery. Electrical equipment of machines.
BS EN 61069, Parts 1-8	1991-1999	Industrial-process measurement and control. Evaluation of system properties for the purpose of system assessment.
BS EN 61310, Parts 1,2,3	2008	Safety of machinery. Indication, marking and actuation.
BS EN 61496, 3 parts	2004 - 2008	Safety of machinery. Electro-sensitive protective equipment.
PIAC	1988	Printing industry advisory committee - safety at power operated paper cutting guillotines

Appendix 4 - Machinery Regulations (Health and Safety Executive, 2018)

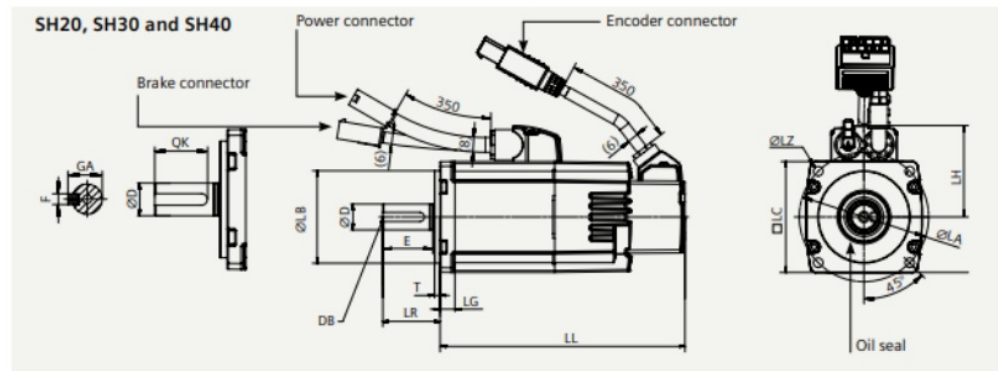
SIMOTICS S-1FL6 Low Inertia for high dynamic performance

Motor

Technical data								
Article number 1FL6	022-2AF	024-2AF	032-2AF	034-2AF	042-2AF	044-2AF	052-2AF	054-2AF
Shaft height (SH)	20		30		40		50	
Rated power (kW) ¹⁾	0.05	0.10	0.20	0.40	0.75	1.00	1.50	2.00
Horsepower (HP)	0.07	0.14	0.27	0.54	1.02	1.36	2.04	2.72
Rated torque (Nm)	0.16	0.32	0.64	1.27	2.39	3.18	4.78	6.37
Rated speed (rpm)	3000							
Maximum torque (Nm)	0.48	0.96	1.91	3.82	7.2	9.54	14.3	19.1
Maximum speed (r/min)	5000							
Rated current (A)	1.2	1.2	1.4	2.6	4.7	6.3	10.6	11.6
Maximum current (A)	3.6	3.6	4.2	7.8	14.2	18.9	31.8	34.8
Torque constant (Nm/A)	0.14	0.29	0.48	0.49	0.51	0.51	0.46	0.55
Moment of inertia (10 ⁻⁴ kg·m ²) (with brake)	0.031 (0.038)	0.052 (0.059)	0.214 (0.245)	0.351 (0.381)	0.897 (1.06)	1.15 (1.31)	2.04 (2.24)	2.62 (2.82)
Thermal class	B (130 °C)							
Degree of protection	IP65							
Recommended load to motor inertia ratio	Max. 30x				Max. 20x		Max. 15x	
Encoder types	Incremental encoder TTL 2500 ppr; Absolute encoder single-turn 21-bit (available in the 2nd half of 2016)				2nd half of 2016)			
Type of construction	IM B5 (IM V1 and IM V3)							
Weight (kg) (with brake)	0.47 (0.70)	0.63 (0.86)	1.02 (1.48)	1.46 (1.92)	2.8 (3.68)	3.39 (4.20)	5.35 (6.76)	6.56 (8.00)
Operating temperature	0 – 40 °C (without any restrictions)						0 – 30 °C (without any restrictions)	
Operating humidity	90% RH maximum (no condensation at 30 °C)							
Vibration severity grade	Grade A							
Radial runout tolerance	Class N							
Installation altitude	≤ 1000 m (without power derating); > 1000 m and up to 5000 m (with power derating)				up to 5000 m	(with power derating)		
Standards								
Holding brake data ²⁾								
Holding torque (Nm)	0.32 Nm		1.27 Nm		3.18 Nm		6.37 Nm	
Rated voltage (V)	24 V DC ± 10%							
Opening time (ms)	35		75		105		90	
Closing time (ms)	10		10		15		35	
Rated current (A)	0.25		0.3		0.35		0.57	

Appendix 5 - 1FL60422AF211AA1 Specifications (SIEMENS, 2016)

Shaft height																Without brake		With brake				
	Type	LC	LA	LZ	LB	LH	LR	T	LG	D	DB	E	QK	GA	F	LL	KB1	LL	KB1	KB2	KL1	KL2
20	1FL6022-2AF	40	46	4.5	30	40	25	2.5	6	8	M3x8	22	17.5	9	3	86	—	119	—	—	—	—
	1FL6024-2AF	40	46	4.5	30	40	25	2.5	6	8	M3x8	22	17.5	9	3	106	—	139	—	—	—	—
30	1FL6032-2AF	60	70	5.5	50	50	31	3	8	14	M4x15	26	22.5	16	5	98	—	132.5	—	—	—	—
	1FL6034-2AF	60	70	5.5	50	50	31	3	8	14	M4x15	26	22.5	16	5	123	—	157.5	—	—	—	—
40	1FL6042-2AF	80	90	7	70	60	35	3	8	19	M6x16	30	28	21.5	6	139	—	178.3	—	—	—	—
	1FL6044-2AF	80	90	7	70	60	35	3	8	19	M6x16	30	28	21.5	6	158.8	—	198.1	—	—	—	—
50	1FL6052-2AF	100	115	9	95	—	45	3	12	19	M6x16	40	28	21.5	6	192	143.5	226	177.5	32.5	135	80
	1FL6054-2AF	100	115	9	95	—	45	3	12	19	M6x16	40	28	21.5	6	216	167.5	250	201.5	32.5	135	80



Appendix 6 - 1FL60422AF211AA1 Dimensions (SIEMENS, 2016)

Technical data – SINAMICS V90 servo drive

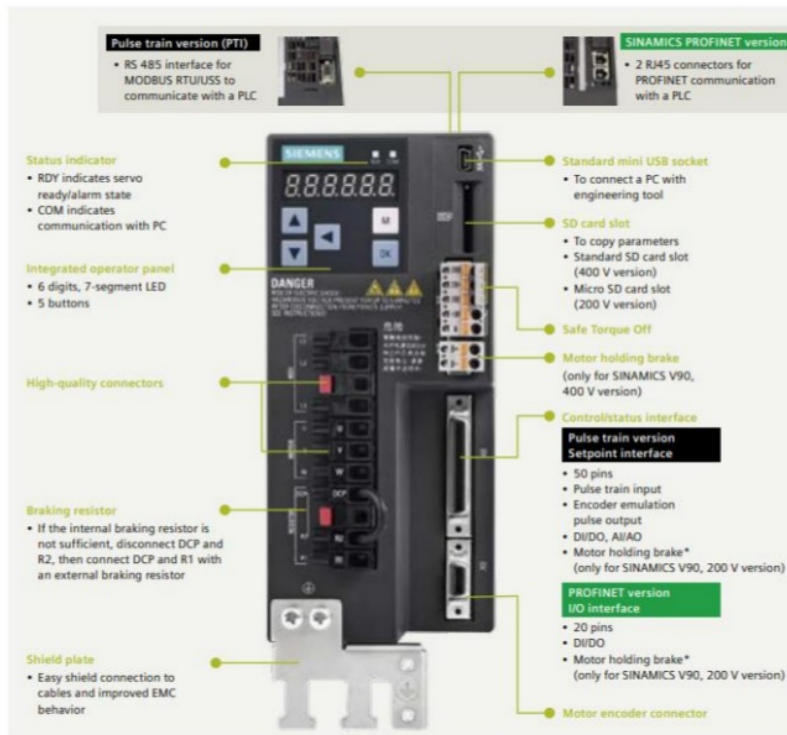
Line supply		200 ... 240 V 1AC/3AC							
Article No.	Pulse train: 6SL3210-5F PROFINET: 6SL3210-5F	B10-1UA0 B10-1UF0	B10-2UA0 B10-2UF0	B10-4UA1 B10-4UF1	B10-8UA0 B10-8UF0	B11-0UA1 B11-0UF1	B11-5UA0 B11-5UF0	B12-0UA0 B12-0UF0	
Max. motor power (kW)		0.1	0.2	0.4	0.75	1	1.5	2	
Rated output current (A)		1.2	1.4	2.6	4.7	6.3	10.6	11.6	
Max. output current (A)		3.6	4.2	7.8	14.1	18.9	31.8	34.8	
Voltage		1/3AC 200 V ... 240 V (–15%/+10%)				3AC 200 V ... 240 V (–15%/+10%)			
Line supply	Frequency	50 Hz				60 Hz, (–10%/+10%)			
	Capacity (kVA) (1AC)	0.5	0.7	1.2	2	—	—	—	
	Capacity (kVA) (3AC)	0.5	0.7	1.1	1.9	2.7	4.2	4.6	
Cooling		Natural cooling				Fan cooling			
Frame size		FSA*		FSB	FSC	FSD			
Dimensions WxHxD (mm)		45x170x170*		55x170x170	80x170x195	95x170x195			
Weight approx. (kg)		1.07		1.20	1.94	2.49			

Appendix 7 - SINAMICS V90 Servo Drive (SIEMENS, 2016)

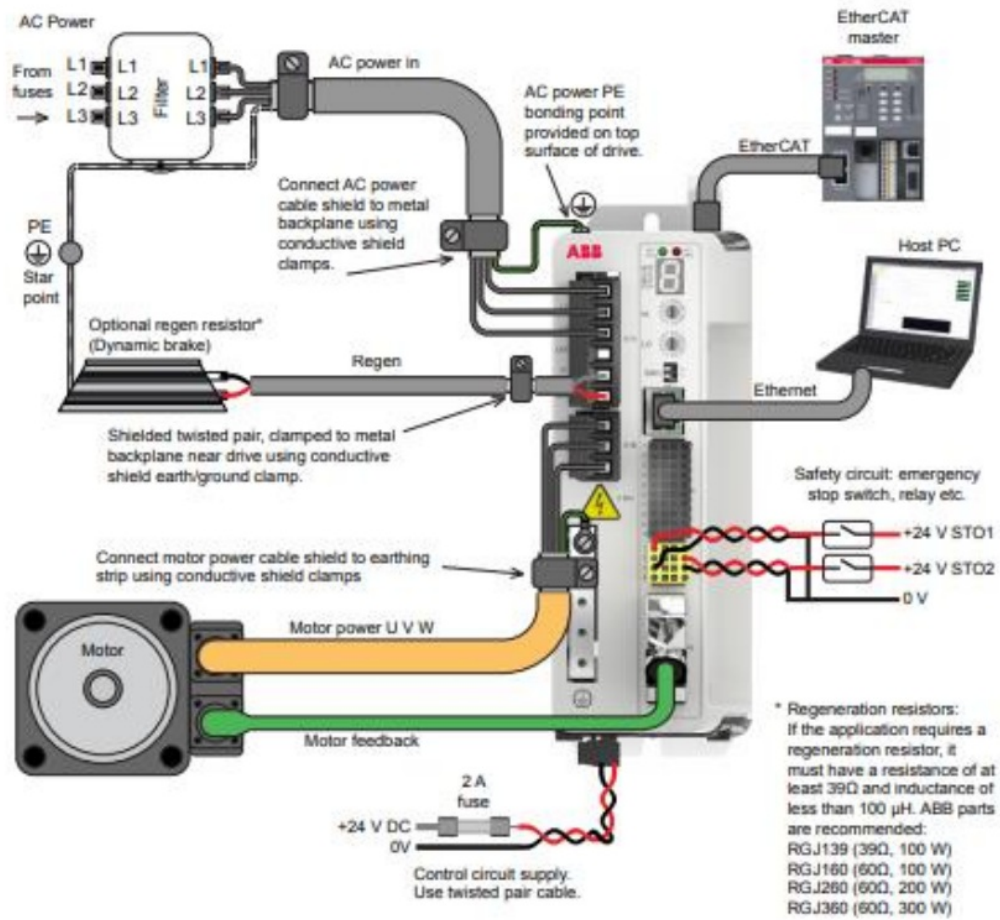
Control features – SINAMICS V90 servo drive

Control modes		
		SINAMICS V90 Pulse train version (PTI)
Control modes		- Pulse train input position control (PTI) - Internal position control (IPos), setpoints selected using a combination of digital inputs, or Modbus/US5 - Speed control (S) - Torque control (T) - Compound controls, switches between position control, speed control, and torque control - Jog using buttons on the integrated operator panel
		SINAMICS V90 PROFINET (PN)
Speed control		PROFINET or internal speed setpoint
		PROFINET or set using a parameter
Pulse train input position control	Speed input	External analog input or internal speed setpoint
	Torque limit	External analog input or set using a parameter
	Max. pulse frequency	- Differential line driver (5 V), 1 MHz - Optical coupler (24 V), 200 kHz
Torque control mode	Multiplying factor	Electronic gear ratio (A/B), A:1-65535, B:1-65535, 1/50<A/B<200
	Torque limit	External analog input or set using a parameter
	Torque input	External analog input or internal torque setpoint
		Set using a parameter

Appendix 8 - SINAMICS V90 Control Modes (SIEMENS, 2016)



Appendix 9 - SINAMICS V90 Servo Drive Labelled Diagram (SIEMENS, 2016)



Appendix 10 - ABB System Connections Diagram (ABB Automation, 2019)

e-Series performance and specification

220 V motors

Frame size		ESM04	ESM06	ESM08	ESM13				
Catalog Number		X-101-302	X-201-302	X-401-302	X-751-302	B-751-302	B-102-202	B-152-302	B-202-202
Rated Power	Watts	100	200	400	750	750	1000	1500	2000
General									
Peak torque	Nm	0.95	1.91	3.81	7.16	7.17	14.31	14.31	28.65
Peak current	A	3	4.8	8.1	14	11.3	15.3	21.2	27
Continuous stall torque	Nm	0.32	0.64	1.27	2.39	2.39	4.78	4.78	9.55
Continuous current	A _{nom}	1	1.6	2.6	4.3	3.8	5.1	6.9	9
Rated speed	rpm	3000	3000	3000	3000	3000	2000	3000	2000
Rated Voltage	V					220			
Electrical									
Torque constant	Nm/A	0.32	0.46	0.47	0.56	0.77	1.02	0.74	1.14
Voltage constant	V _{nom} /krpm	23.7	28	32.8	37.3	42.5	61.7	44.7	68.9
Resistance	ohms	20.5	6.4	3.15	1.48	2.18	1.22	0.65	0.58
Inductance	mH	27.5	16.2	11	10.1	7.7	6.7	3.6	3.8
Electrical time constant	ms	1.22	2.53	3.5	5.74	3.53	5.49	5.48	6.52
Mechanical									
Rotor inertia with brake	kg-cm ²	NA	0.23	0.34	1.03	2.39	6.96	6.96	12.84
Rotor inertia without brake	kg-cm ²	0.04	0.17	0.28	0.9	2.26	6.26	6.26	12.14
Max. speed	rpm	6000	6000	6000	5000	3800	2800	3800	2800
Mechanical time constant	ms	1.01	3.36	0.83	0.59	1.64	1.1	1.24	0.86
Number of motor poles	-					8			
Weight with brake	kg	NA	1.4	1.9	3.8	4	8.1	8.1	11.8
Weight without brake	kg	0.5	1	1.4	2.4	3.2	6.5	6.5	10.2

Appendix 11 - ESM08X-751-302-T1N0A00 Performance and Specifications (ABB Automation, 2019)

Environmental									
Insulation class	-					F			
Operating temperature range	°C					0 to 40			
Operating humidity	%		80				90		
Storage temperature range	°C					-20 to 60			
Temperature coefficient	°C/W	1.276	0.256	0.154	0.117	0.088	0.064	0.062	0.048
Max radial load *	N	50	124	146	167	368	424	330	491
Max thrust load	N	10	23	23	22	68	175	89	220
Brake data									
Rated voltage	VDC ±10%					24			
Current	A	NA	0.26		0.43		0.82		
Input power	W	NA	6.3		10.4		19.5		
Static friction torque	N-m (min)	NA	2		3		20		
Armature release time	ms (max)	NA	17		35		27		
Armature pull-in time	ms (min)	NA	32		25		76		

* Radial force applied at the end of motor shaft

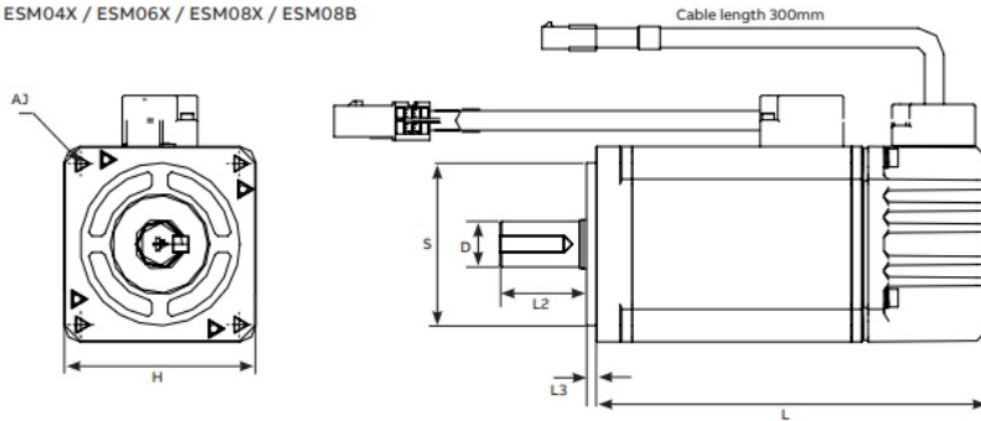
Appendix 12 - ESM08X-751-302-T1N0A00 Performance and Specifications (ABB Automation, 2019)

e-Series motor dimensions

Catalog Number	Motor Length (L) mm		Shaft		Frame	Spigot		Mounting Holes	
	W/O brake	W/brake	Length (L2) mm	Diameter (D) mm	Width (H) mm	Depth (L3) mm	Diameter (S) mm	Diameter (A2) mm	PCD mm
ESM04X-101-302-xx0A00	98.5	NA	25	8	40	2.5	30	4.5	46
ESM06X-201-302-xx0A00	101	139.5	30	14	60	3	50	5.5	70
ESM06X-401-302-xx0A00	123	161.5	30	14	60	3	50	5.5	70
ESM08X-751-302-xx0A00	122.2	160.5	40	19	80	3	70	6.5	90
ESM08B-751-302-xx0A00	147.5	182.7	35	16	86	3	80.4	6.5	100

e-Series motor drawings

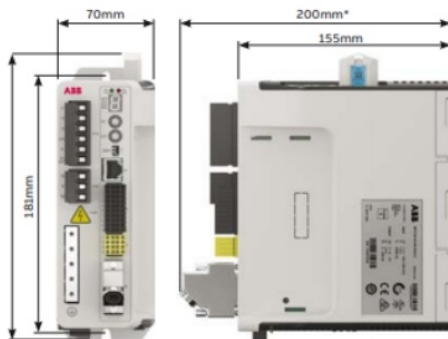
ESM04X / ESM06X / ESM08X / ESM08B



Appendix 13 - ESM08X-751-302-T1N0A00 Motor Dimensions and Drawing (ABB Automation, 2019)

Technical specifications

MicroFlex e190



*Approximate dimensions. Allow extra space for feedback and other control cables

Technical specification	
Voltage/Frequency	Single- or three-phase 105-264 V AC/ 48-63 Hz
Efficiency	>95%
PWM switching frequency / control	8 kHz / Space Vector Modulation
Motor types	Asynchronous motors (standard induction, servo) and synchronous motors (servo, high torque), linear servo motors
Braking resistor (external)	0.25 kW nominal/ 2.7 kW peak 10% duty with 57 W nominal (min 39 W max 100 W)
Product compliance	
Approvals	CE, cUL CE, cUR
EMC	EN61800-3 C2 emissions with external filter (50 m motor cable limit)
Environmental limits	
Operating temperature	1.6 A unit 0-50°C (de-rating applies to 45 to 50°C max) 3 / 6 / 9 A units 0-55°C no derating
Altitude	Rated 1000 m / 3300 ft De-rate 1.1% / 100 m (330 ft) > 1000 m (3300 ft)
Degree of Protection	IP20 cabinet installation
Safety	
Safe torque-off (STO) as standard	Two-channel STO to IEC 61800-5-2, SIL3 PLe
I/O	
4 x digital inputs	Opto-isolated 24 V 2 inputs can be programmed as fast position latch inputs 1 µs (feedback device dependent) or pulse direction inputs (max 2 MHz)
3 x digital outputs	Opto-isolated 24 V PNP, 50 mA per channel Configurable / programmable function
1 x ±10 V analog inputs 1 x ±10 V analog output	12 bit (16 bit with oversampling). Analog speed / torque control with emulated encoder output.
7 segment status display with sequenced error codes	For error and communications notification to quickly identify problems and minimize downtime
NET RUN & NET ERR LEDs	Indicate EtherCAT status of operation in accordance with EtherCAT Technology Group (ETG) guidelines

Technical specification	
Communications	
EtherCat (E2=IN E1=Out)	2 x RJ45 for daisy chain connection LED indication built into RJ45 sockets Drive profile: DS402/ IEC61800-7-1
Powerlink (E2=IN E1=Out)	2 x RJ45 for daisy chain connection LED indication built into RJ45 sockets Drive profile: DS402/ IEC61800-7-1
PROFINET IO	Communication with PLCs / Industrial PCs Drive operation can be customized with a MINT program
EtherNet/IP (E3 port only)	Note: CiP™ sync not supported Drive operation can be customized with a MINT program
Modbus TCP (E3 port only)	Communication with PLCs / Industrial PCs / IO / HMIs. Drive operation can be customized with a MINT program
E3 Ethernet configuration port	MINT PC support tools for host PC interfacing in Visual Basic, Visual C, LabView
Motor feedback	
Universal digital feedback	Incremental encoder + Halls, SSI (Synchronous Serial Interface), BiSS B, EnDat 2.1/2.2, 1 V pk-pk Sin/Cos, SmartAbs, SmartInc, Hiperface (8 V)
Dual encoder input	For line shaft following or dual loop control (position / velocity and commutation) to eliminate mechanical errors
Ethernet and motor encoder feedback interfaces	Highly integrated with minimal latency, optimized for demanding motion applications
Resolver	Support by option OPT-MF-201 adapter

Appendix 14 - MFE190-04UN-06A0-2 MicroFlex e190 Drive Specifications (ABB Automation, 2019)

Sales Quote SQ000215

4. December 2019
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University of Wales
Sam Harries
Trinity Saint David
College Street
Lampeter, SA48 7ED

SMS Machine Automation
Unit 23, Longfields Road,
Carlton
Barnsley, South Yorkshire S71 3HT

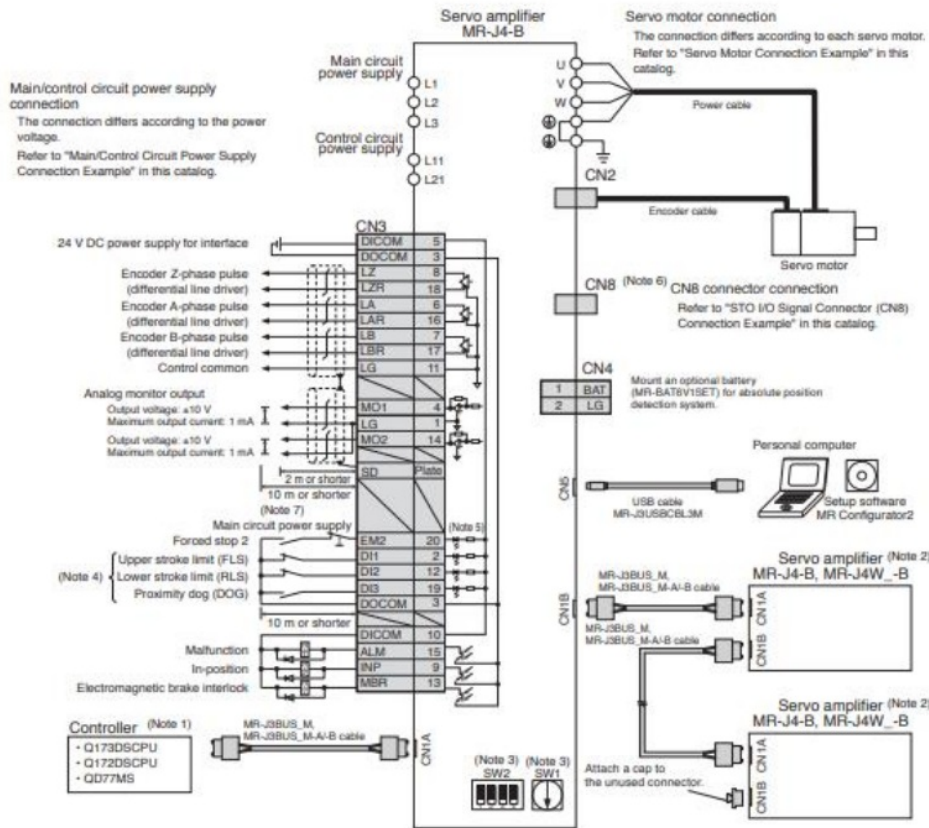
Your Reference	Valid to	Salesperson	Payment Terms	Shipment Method
	1. January 2020	Kirsty Thomas	PROFORMA	

No.	Description	Quantity	Unit Price Excl. VAT	VAT %	Line Amount Excl. VAT
ABSM10 17	ABB ESM08X-751-302-T1N0A00 200V 750W 80 Frame	1 Piece	381.00	20	381.00
ABB- AXD- 041038	CBL050-EPP-PB06 Power & brake cable for ESM04/06/08	1 Piece	31.00	20	31.00
ABB- AXD- 042182	CBL050-EFP-F22 Feedback cable - 17bit INC encoder for ESM04/06/08	1 Piece	52.00	20	52.00
ABB- AXD- 038568	MFE190-04UN-06A0-2 MicroFlex e190 (Ethernet slave, without Mint programming)	1 Piece	548.00	20	548.00
Lead time 2-3 weeks ARO					
Subtotal					1,012.00
20% VAT					202.40
Total £ Incl. VAT					1,214.40

Appendix 15 - SMS Automation Quote for ABB Alternative Solution (SMS Machine Automation, 2019)

MR-J4-B Standard Wiring Diagram Example

MR-J4-B



Appendix 16 - MR-J4-70B Connections (Mitsubishi Electric, 2012)

HG-MR Series (Ultra-low Inertia, Small Capacity) Specifications

Rotary servo motor model		HG-MR	053(B)	13(B)	23(B)	43(B)	73(B)
Compatible servo amplifier model		MR-J4- MR-J4W -	Refer to "Combinations of Rotary Servo Motor and Servo Amplifier" on p. 2-4 in this catalog.				
Power supply capacity ¹⁾		[kVA]	0.3	0.3	0.5	0.9	1.3
Continuous running duty	Rated output	[W]	50	100	200	400	750
	Rated torque ^(Note 3)	[N·m]	0.16	0.32	0.64	1.3	2.4
Maximum torque		[N·m]	0.48	0.95	1.9	3.8	7.2
Rated speed		[r/min]	3000				
Maximum speed		[r/min]	6000				
Permissible instantaneous speed		[r/min]	6900				
Power rate at continuous rated torque	Standard	[kW/s]	15.6	33.8	46.9	114.2	97.3
	With electromagnetic brake	[kW/s]	11.3	28.0	37.2	98.8	82.1
Rated current		[A]	1.0	0.9	1.5	2.6	5.8
Maximum current		[A]	3.1	2.5	5.3	9.0	20
Regenerative braking frequency ²⁾	MR-J4-	[times/min]	(Note 4)	(Note 4)	1180	713	338
	MR-J4W -	[times/min]	7310	3620	1170	710	846
Moment of inertia J	Standard	[× 10 ⁻⁴ kg·m ²]	0.0162	0.0300	0.0865	0.142	0.586
	With electromagnetic brake	[× 10 ⁻⁴ kg·m ²]	0.0224	0.0362	0.109	0.164	0.694
Recommended load to motor inertia ratio ^(Note 1)			35 times or less	32 times or less			
Speed/position detector			Absolute/incremental 22-bit encoder (resolution: 4194304 pulses/rev)				
Oil seal			None	None (Servo motors with oil seal are available. (HG-MR_J))			
Insulation class			130 (B)				
Structure			Totally enclosed, natural cooling (IP rating: IP65) ^(Note 2)				
Environment ³⁾	Ambient temperature		0 °C to 40 °C (non-freezing), storage: -15 °C to 70 °C (non-freezing)				
	Ambient humidity		80 %RH maximum (non-condensing), storage: 90 %RH maximum (non-condensing)				
	Ambience		Indoors (no direct sunlight); no corrosive gas, inflammable gas, oil mist or dust				
	Altitude		1000 m or less above sea level				
Vibration resistance ⁴⁾			X: 49 m/s ² Y: 49 m/s ²				
Vibration rank			V10 ⁵⁾				
Permissible load for the shaft ⁶⁾	L	[mm]	25	25	30	30	40
	Radial	[N]	88	88	245	245	392
	Thrust	[N]	59	59	98	98	147
Mass	Standard	[kg]	0.34	0.54	0.91	1.4	2.8
	With electromagnetic brake	[kg]	0.54	0.74	1.3	1.8	3.8

Appendix 17 - MG-MR Series Specifications

HG-MR Series Special Shaft End Specifications

Motors with the following specifications are also available.

D-cut shaft (Note 1): 50 W and 100 W

[Unit: mm]

Key shaft (with key) (Note 1, 2): 200 W, 400 W, and 750 W

Model		Variable dimensions								
		T	S	R	Q	W	QK	QL	U	Y
HG-MR	23(B)K, 43(B)K	5	14h6	30	26	5	20	3	3	M4 screw Depth: 15
	73(B)K	6	19h6	40	36	6	25	5	3.5	M5 screw Depth: 20

[Unit: mm]

Appendix 18 - HG-MR Shaft Specifications (Mitsubishi Electric, 2012)

- HG-MR73(B)



Appendix 19 - HG-MR-73B Dimensions (Mitsubishi Electric, 2012)

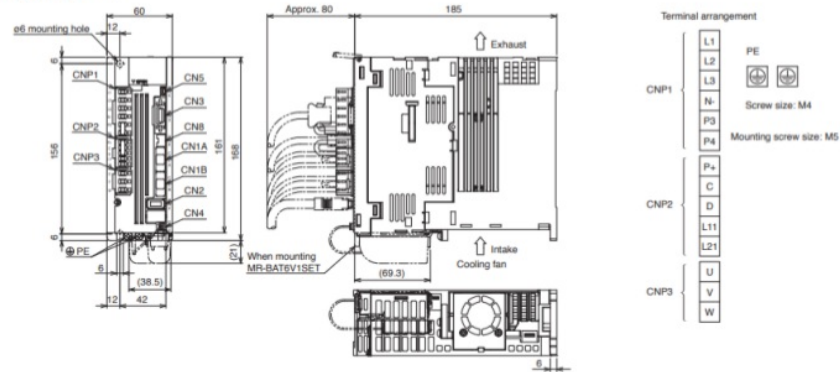
MR-J4-B (SSCNET III/H Interface) Specifications
MR-J4-B

Servo amplifier model MR-J4-		10B	20B	40B	60B	70B	100B	200B	350B	500B	700B	
Output	Rated voltage	3-phase 170 V AC										
	Rated current [A]	1.1	1.5	2.8	3.2	5.8	6.0	11.0	17.0	28.0	37.0	
Main circuit power supply	Voltage/frequency (Note 1)	3-phase or 1-phase 200 V AC to 240 V AC, 50/60 Hz					3-phase 200 V AC to 240 V AC, 50/60 Hz					
	Rated current [A]	0.9	1.5	2.6	3.2 (Note 9)	3.8	5.0	10.5	16.0	21.7	28.9	
	Permissible voltage fluctuation	3-phase or 1-phase 170 V AC to 264 V AC					3-phase 170 V AC to 264 V AC					
	Permissible frequency fluctuation	±5% maximum										
Control circuit power supply	Voltage/frequency	1-phase 200 V AC to 240 V AC, 50/60 Hz										
	Rated current [A]	0.2								0.3		
	Permissible voltage fluctuation	1-phase 170 V AC to 264 V AC										
	Permissible frequency fluctuation	±5% maximum										
	Power consumption [W]	30								45		
Interface power supply		24 V DC ± 10% (required current capacity: 0.3 A (including CN8 connector signal))										
Control method		Sine-wave PWM control/current control method										
Tolerable regenerative power of the built-in regenerative resistor (Note 2, 3) [W]		-	10	10	10	20	20	100	100	130	170	
Dynamic brake		Built-in (Note 4)										
SSCNET III/H command communication cycle (Note 12)		0.222 ms, 0.444 ms, 0.888 ms										
Communication function		USB: Connect a personal computer (MR Configurator2 compatible)										
Encoder output pulse		Compatible (A/B/Z-phase pulse)										
Analog monitor		2 channels										
Fully closed loop control (Note 10)		Available (Note 11)										
Load-side encoder interface (Note 8)		Mitsubishi high-speed serial communication										
Protective functions		Overcurrent shut-off, regenerative overvoltage shut-off, overload shut-off (electronic thermal), servo motor overheat protection, encoder error protection, regenerative error protection, undervoltage protection, instantaneous power failure protection, overspeed protection, error excessive protection, magnetic pole detection protection, linear servo control fault protection										
Safety function		STO (IEC/EN 61800-5-2)										
Safety performance	Standards certified by CB	EN ISO 13849-1 Category 3 PL d, EN 61508 SIL 2, EN 62061 SIL CL 2, EN 61800-5-2 SIL 2										
	Response performance	8 ms or less (STO input OFF → energy shut-off)										
	Test pulse input (STO) (Note 7)	Test pulse frequency: 1 Hz to 25 Hz Test pulse off time: 1 ms maximum										
	Mean time to dangerous failure (MTTFd)	100 years or longer										
	Diagnostic coverage (DC)	Medium (90% to 99%)										
Probability of dangerous Failure per Hour (PFH)		1.68×10^{-10} [1/h]										
Compliance to standards		Refer to "Conformity with global standards and regulations" on p. 22 in this catalog.										
Structure (IP rating)		Natural cooling, open (IP20)					Force cooling, open (IP20)			Force cooling, open (IP20) (Note 5)		
Close mounting		Possible (Note 6)									Not possible	
Mass [kg]		0.8	0.8	1.0	1.0	1.4	1.4	2.1	2.3	4.0	6.2	

Appendix 20 - MR-J4-B Technical Specifications (Mitsubishi Electric, 2012)

●MR-J4-70B (Note 1)

●MR-J4-100B (Note 1)



[Unit: mm]

Appendix 21 - MR-J4-70B Dimensions (Mitsubishi Electric, 2012)

269283	MR-J4-70B-RJ	750W Servo amplifier (SSCNET III bus control) (200V 1-phase or 3-phase) RJ Type	£682.50
248670	HG-MR738	Ultra low-inertia 750W Servo motor with brake (2.4Nm continuous, 7.2Nm peak)	£829.00
160227	MR-PWS1CBL2M-A1-H	Power cable; for HG-KN, HG-KR, -MR, high flex, 2m (motor shaft)	£57.50
161554	MR-J3ENCBL2M-A2-L	2m encoder cable for K and M Type motors	£32.50
210802	MR-PWS3CBL2M-A2-L	2m power cable K and M Type motors	£50.00

Appendix 22 - (Mitsubishi 2019, Personal Communication, Dec)

SGEE6003- Major Project Proposal

Sam Harries

Summary

The Finishing Robot in the CIM system in G8 has a linear drive system which utilises a DC motor. This motor is controlled using an obsolete Keyence PLC, with relays and a slowdown resistor for two speeds and an incremental encoder connected to the motor for position feedback. This system is slow and outdated, lacks diagnostic facilities and has poor positioning and speed control. The purpose of the project is to bring the system in line with Industry 4.0 standards.

Who will be Involved

This project will primarily be done by the author, in consultation with college tutors Rob Davies and Mike Hall.

Budget

The budget for this project is £1000.

Completion

The project must be built and tested and documented by April 24th 2020.

Requirements

Replace the existing obsolete system, with a new panel containing controls, safety features, a PLC and a drive.

The features required of the updated system would include; position and speed control, interfaced with existing PROFINET network, linked to HMI with a series of new screens added, to provide diagnostics and manual controls for maintenance and fault finding of the linear drive. These will enable a greater use in educational modules to assist teaching of servo systems and integrated automation technologies.

There is also a requirement for two modes of operation; manual from HMI screen, and automatic from the Mitsubishi robot. The HMI must also contain a mimic animation of the robot's movement in real-time. Safe stopping is also required as a safety feature.

Solution 1

Replace the existing DC motor with an AC Servo and use a gearbox to lower the RPM of the motor.

Solution 2

Replace the existing DC motor with an AC Induction Motor and drive it with a low RPM and higher torque.

Solution 3

Build a new H bridge circuit to drive the existing DC motor to give it more control.

Student Signature:

Sam Harries

04 / 10 / 19

Tutor Signature:

R. Davies

04 / 10 / 19

FINAL GRADE

GENERAL COMMENTS

Instructor

74/100

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GRADING FORM: NEW CSG-RUBRIC

**DAVID
HARRIES**

63

1. ENGAGEMENT WITH LITERATURE



Engagement with an appropriate range of research-informed literature, including sources retrieved independently. However, not all information has been critically evaluated and explained. Good evidence of research for literature review. Evidence of extensive research was demonstrated. (8/10) A reasonable list of citations but date accessed is missing from online

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sources. Harvard method mostly used but not always applied correctly. A wide range of reliable technical sources were used. (3/5) Total = 11/15

2. KNOWLEDGE AND UNDERSTANDING



Generally good information provided setting the background and context of the project. Project explained as the addition of a robot to the existing CIM system at Coleg Sir Gar. Wider issues were covered in the report. (7/10) Good references to standards with some explanations provided. However, further explanations were expected of how they relate to the project. Detailed consideration of all aspects of ethical engineering were explained in detail, however some too generic and didn't relate directly to the project. (6/10) Some consideration given. Use of efficient components such as the motor and utilisation of Profi-Energy. (4/5) Risk table needs an explanation with some consideration given to health and safety but no risk assessment provided. Risk assessment of negative factors carried out in the form of a risk v impact matrix. (3/5) Total = 20/30

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3. COGNITIVE AND INTELLECTUAL



Clearly defined and explained. Problem identified as poor positioning of the arm and low maximum speed (4/5) Detailed and clear, setting out the requirement of the project. FDS explained including set speeds, use of interlock for safety and the need for a new HMI screen (7/10) A good section provided that concludes the report and plans for the completion of

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the project. More descriptive than evaluative (4/5)
Total = 19/25

4. PRACTICAL APPLICATION



Good consideration given for 3 solutions. However, not all aspects of solutions 2 and 3 were considered. Correct choice of final solution made. Detailed scoring system used to assess each solution (5/5) Good evidence provided by means of WBS, but Gantt chart could be more detailed and risk matrix lacks explanation. No risk assessment provided for health and safety. Detailed 3 layer WBS was devised, Gantt was a simplistic linear chart (6/10)
Total = 11/15

11/15

5. TRANSFERABLE SKILLS



Excellent summary given. A good understanding of the project could be gleaned (4/5) Generally good. Well written with a good style, easy to read. Clear diagrams and images with a good appendix. However, not all figures have been explained. Generally very well written and presented (4/5) No word count penalty applied. 3910 words declared (5/5) Total = 13/15

13