FINAL PROJECT
Ladder Logic Programming Assignment

Completion Deadline – 3pm on Tuesday, December 5th, 2023.

INSTRUCTIONS:

This assignment is to be completed **individually** (without assistance from any other person).

Do not discuss your solution with any other student, allow any other student to view your program while you are working on the assignment, or provide a copy of your program to any other student.

Note that all of the submitted programs will be compared, and severe grading penalties will be assigned to all programs that show blatant copying and/or sharing of information.

While completing the assignment, you may utilize any of your **lecture notes**, the PowerPoint slides, or any other material provided via **D2L** for this course.

Note – "On-line" resources, including forums and other websites that allow people to post information and/or answer questions, may **NOT** be utilized when completing this exam.

ASSIGNMENT: You are tasked with **creating a ladder-logic based program** that, when downloaded into the PLC and the PLC is switched to RUN mode, will provide the operational logic* for a simple conveyor-driven, production-line oven that will be used in a local confectionary. (* - the exact logic requirements are provided on page 4 of this document).

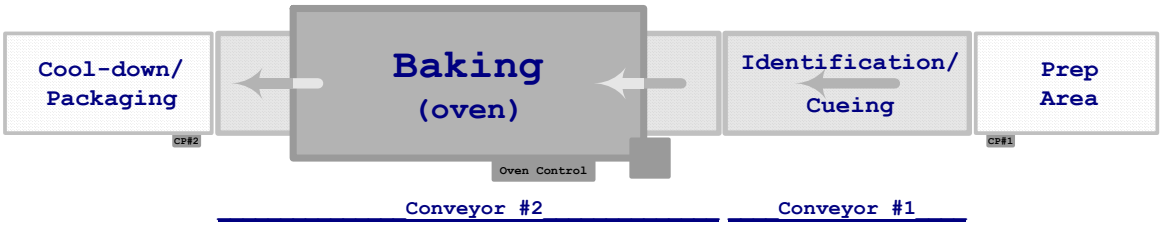


Figure 1 – Simplified System Diagram (top view)

While completing this assignment, you will have access to the Q-215 Electric Machines lab in order to utilize both the RSLogix software that is available on the lab's desktop computers and several of the Lab Volt benches that will contain functional PLC setups in order to test and debug your ladder logic programs.

EVALUATION: The operation of the sorting system will be divided into three operational states:

STARTUP, **NORMAL OPERATION**, **SHUTDOWN,** and **REVERSE OPERATION**

You completed program will be evaluated on whether or not it provides the proper operational logic for each of the operational states with the following weighting:

SYSTEM STARTUP	**20%**	**(-5pts after milestone deadline)**
NORMAL OPERATION	**45%**	**(-10pts after milestone deadline)**
SHUTDOWN	**20%**	
REVERSE OPERATION	**15%**	

Note – Since the system can only operate "normally" after it has been properly "started", NORMAL OPERATION will only be evaluated if STARTUP is fully functional. Similarly, SHUTDOWN will only be evaluated if NORMAL OPERATION is fully functional, and REVERSE OPERATION will only be evaluated if SHUTDOWN is fully functional.

Milestone Requirements: You must complete and verify the operation of **SYSTEM STARTUP** by:

3pm on Wednesday, November 8th

You must complete and verify the operation of **NORMAL OPERATION** by:

3pm on Wednesday, November 29th

COMPLETION REQUIREMENTS: Once you have written and tested your program, you must:

a) **Verify its operation** to the instructor by using one of the scale-model conveyor systems that are available in Q-215 to demonstrate its proper operation, and

b) **Submit an electronic copy of your program** at the completion of the "final demo".

Final Completion Deadline – 3pm on Tuesday, December 5th, 2023.

PROPOSED SYSTEM – DESCRIPTION OF COMPONENTS:

The proposed system will be used to bake two different types of cookies that will be produced by the confectionary, ideally with no required interaction (during normal operation) from the production-line workers once the system is operational.

The system consists of two conveyor units, each of which performs an important function with respect to the overall operation of the system (see Figure 1):

1) Identification/Cueing of Cookie Trays, and
2) Baking of the Cookies.

CONVEYOR #1 – Identification/Cueing

Production line workers, located at the "prep area", place the raw cookie material in special baking trays and then slide the trays onto conveyor #1 to begin the baking process. The trays travel down to the end of conveyor one where they are held in-cue until conveyor #2 is ready to receive them. Additionally, optical detectors located at the end of conveyor #1 are used to detect the type of cookie that is cued for baking.

CONVEYOR #2 – Baking

Conveyor #2 slowly transports the trays through the long oven that is used to bake the cookies and then pushes the trays onto the "cooldown & packaging" platform, at which point production line worker will begin to package the cookies.

An optical detector, located near the entrance of the oven, is used in conjunction with the detector located at the end of conveyor #1 to maintain an adequate spacing between the individual baking trays as they are transported through the oven. The rate of travel and the oven temperature are both based upon the type of cookie being baked, as determined by the optical detectors located at the end of conveyor #1.

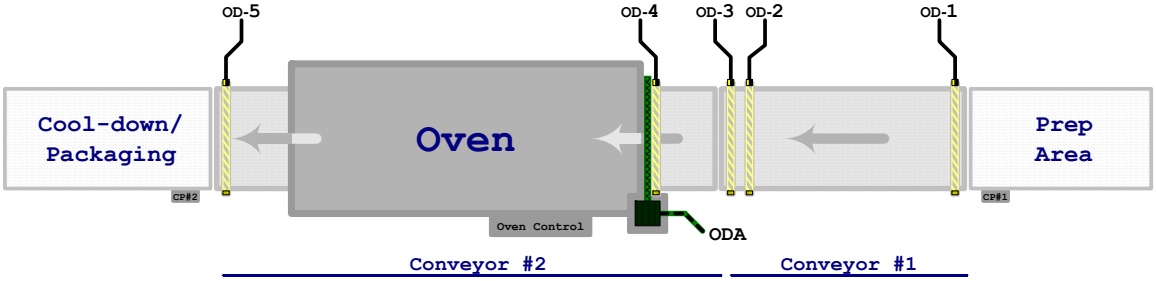


Figure 2 – System Diagram with Optical Detectors shown (top view)

CONVEYOR MOTORS & SUPPLY

Both conveyors will be driven by 208V, 3Φ, Y-connected, squirrel-cage induction machines.

Conveyor #1 needs to be able to operate in both the forward and reverse directions, but only at a single speed, the speed of which is predetermined by the selected motor's gearbox ratio. Since the conveyor only operates at one speed, a ***contactor-based supply*** will be utilized for its motor.

Conveyor #2 needs to be able to operate in both the forward and reverse directions and at a variety of speeds. For this reason, an Allen-Bradley, PowerFlex 40 ***VFD*** will be used to supply the drive motor of conveyor #2.

OVEN

The oven is an integral part of conveyor #2. It is used to bake the cookies that have been placed within the specialty baking trays as they travel from the "prep area" to the "packaging" location. Although the design and detailed operation of the oven is outside the scope of this assignment, the PLC that is controlling the conveyor system must also control the basic operation of the oven.

When it is time for the oven to operate, a $+24V_{DC}$ signal must be sent to the "**OVEN ENERGIZE**" terminal of the oven's controller in order for the oven's heating elements, circulation fans, and control system to be energized. Once energized, the oven will begin heating to the temperature required by the cookie-type, as defined by a second signal ($0V_{DC}$ – Type 0, $+24V_{DC}$ – Type 1) that must be sent to the "**OVEN PRESET**" terminal of the oven's controller.

Additionally, the operational status of the oven will be denoted by a signal that the oven will provide at the "**OVEN STATUS**" terminal of the oven's controller. When either deenergized or energized but not at the correct operating temperature, $0V_{DC}$ will be present at the OVEN STATUS terminal to denote "***Improper Temperature***". But if the oven has reached the correct temperature after being energized, $+24V_{DC}$ will be present at the OVEN STATUS terminal to denote "***Over Ready***".

SAFETY DEVICES

The system utilizes a set of **Safety Lights** and a **Signal Horn** to provide both visual and audible indication of the system's operational state. These devices are directly wired to and thus energized/controlled by the output module of the PLC.

CONTROL PANELS

The system contains two control panels, CP#1 and CP#2. (*Note – The scale-model "test" systems in the Q-215 lab will utilize a single control panel that includes all pushbuttons and indicators.*)

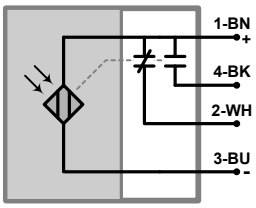
CP#1 is located near the entrance of conveyor #1. This control panel contains **two pushbuttons** (**START** and **STOP**) that are directly connected to the PLC's input module and **five indicator lamps** that are directly wired to the PLC's output module.

CP#2 is located near the exit of conveyor #2. This control panel only contains **one pushbutton** (**REVERSE**) that is directly connected to the PLC's input module and **five indicator lamps** that are directly wired to the PLC's output module.

Note that, although both control panels would normally also contain at least one additional pushbutton (**EMERGENCY STOP**) and additional indicators, the operational logic required for the system to include Emergency Stop and any other functions is outside the scope of this project, and thus those additional buttons and indicators have been omitted from the control panels.

OPTICAL DETECTORS

The **Optical Detectors** utilized in this system are beam-type detectors that trigger when an object breaks their light-beam. Each detector contains a NO/NC contact pair that both actuate when the detector is triggered. The detectors' NO contacts will be connected to the PLC's input module such $+24V_{DC}$ will be supplied to the associated input whenever an object breaks a specific detector's beam.



OVEN DOOR ACTUATOR

An actuated door was added to the oven entrance in order to help reduce heat loss / conserve energy.

The oven door actuator defaults to the "open" position for the oven door. In order for the actuator to close the over door, a $+24V_{DC}$ signal must be sent to the "**OVEN DOOR**" terminal of the oven's controller. Note that the $+24V_{DC}$ signal must be maintained at the "**OVEN DOOR**" terminal in order for the door to remain closed. Removal of the $+24V_{DC}$ signal at the "**OVEN DOOR**" terminal will cause the actuator to re-open the oven door.

PLC – INPUT & OUTPUT SCHEDULE

The following table provides a list of the devices that are directly wired to each of the input and output ports of the PLC. Detailed information regarding the exact function of these devices is provided elsewhere in this document.

PLC – Input & Output Schedule			
Input	**Description**	**Output**	**Description**
0	**STOP (NC PB)**	**0**	**Safety Lights**
1	**Optical Detector OD-1**	**1**	**Signal Horn**
2	**Optical Detector OD-2**	**2**	***System Starting* Indicator**
3	**Optical Detector OD-3**	**3**	***Normal Operation* Indicator**
4	**Optical Detector OD-4**	**4**	***System Shutdown* Indicator**
5	**Optical Detector OD-5**	**5**	***Reverse Operation* Indicator**
6	**START (NO PB)**	**6**	**Conv. #1 – Forward Contactor**
7	**REVERSE (NO PB)**	**7**	**Conv. #1 – Reverse Contactor**
8	**—**	**8**	**OVEN ENERGIZE**
9	**—**	**9**	**OVEN PRESET**
10	**OVEN STATUS**	**10**	**—**
11	**—**	**11**	**OVEN DOOR**
12	**—**	**12**	**—**
13	**—**	**13**	**—**
14	**—**	**14**	**—**
15	**—**	**15**	**—**

SYSTEM NETWORK CONFIGURATION

The following table provides a list of the IP Addresses that must be assigned to each of addressable devices that will be utilized in the system.

Note that, although the configuration of these devices is not an explicit part of this project, each student is responsible for ensuring that the devices have been assigned the proper IP addresses.

System Network Configuration		
Device	**Description**	**IP Address**
PC	**Desktop Computer w/ RSLogix 5000 Software**	**192.169.3.1**
PLC	**Compact Logic – Programmable Logic Controller**	**192.169.3.20**
VFD	**PowerFlex40 – Variable Frequency Drive**	**192.169.3.22**

VFD OPERATING SETTINGS

The following table provides information regarding some of the operational settings for the VFD that must be set by the PLC during system operation.

VFD Operating Frequencies		
Forward Operation	**OVEN PRESET = 0 (Cookie Type #0)**	**14 Hz**
	OVEN PRESET = 1 (Cookie Type #1)	**17 Hz**
Reverse Op.		**30 Hz**

SYSTEM OPERATIONAL LOGIC (Program Specific Requirements):

STARTUP: [from a fully de-energized state]

Pressing & holding the **START** button for at least **1 second** will cause the **Safety Lights** to begin **flashing slowly** (**ON 1 sec ➡ OFF 1 sec ➡ repeat**), after which **releasing** the **START** button will cause the ***System Starting*** **indicator** to **illuminate**, at which point the system is considered to be in **STARTUP**.

Note – Pressing the **STOP** button at this point (before START is pressed a 2nd time) will cause both the ***Safety Lights*** and the ***System Starting*** indicator to shut **OFF**, returning the system back to a fully de-energized state.

While the *System Starting* indicator is illuminated and the Safety Lights are flashing slowly, **pressing** the **START** button will immediately trigger the following ordered set of events:

a) The **Safety Lights** will begin **flashing quickly** (**ON ½ sec ➡ OFF ½ sec ➡ repeat**),

b) The **Signal Horn** will **sound** (**ON**) for **3 seconds ➡ shut OFF** for **1 second ➡ sound** (**ON**) again for **2 seconds ➡ shut OFF**.

c) When the **Signal Horn** finishes cycling **ON/OFF**, the **Oven** will be **energized** (with the ***Cookie Type*** set to a default value of **0**), **conveyor #2** will **start moving** in the **forward** direction, and the **oven door** will **CLOSE**.

When the "***Oven Ready***" signal is **received***, the following set of ordered events will occur:

d) The **Signal Horn** will **sound** (**ON**) for **1 second ➡ shut OFF** for **2 seconds ➡ sound** (**ON**) again for **1 second ➡ shut OFF**.

e) When the **Signal Horn** finishes cycling **ON/OFF**, the ***System Starting*** **indicator** will **shut OFF** and the ***Normal Operation*** **indicator** will **illuminate**, at which point **STARTUP is complete** and the system is considered to be in **NORMAL OPERATION**.

Note – pressing the **STOP** button while the **Safety Lights** are **flashing quickly** during STARTUP will have **no effect** on the operation of the system.

* - Depending on the scale-model system that you are using, the time-delay between ***energizing*** the oven and receiving the ***Oven Ready*** signal may vary. But as long as you trigger step (d) based on the ***Oven Ready*** signal, the varying time delays should not affect the proper operation of your STARTUP procedure.

NORMAL OPERATION: [after STARTUP is complete]

When the system enters **NORMAL OPERATION**, **Conveyor #1** will **start moving forward** and the **Safety Lights** will begin **flashing slowly** (**ON 1 sec ➡ OFF 1 sec ➡ repeat**). Once conveyor #1 is moving, workers may begin placing cookie trays onto conveyor #1.

Note – the logic for NORMAL OPERATION requires constant monitoring of the total number of boxes located on conveyor #2 at any time. See the information section regarding the optical detectors at the end of the LOGIC section of this document.

CONVEYOR #1 – Normal Operation

When a **tray breaks (triggers) OD-3**, the **state** of **OD-2** (**clear – Type 0, triggered – Type 1**) is used to determine the type of tray (***Next Cookie Type***) that has reached OD-3 and then, based on the result, one of the following will happen:

A) If **conveyor #2** is **empty** and:

i. the **OVEN PRESET** is already configured for the ***Next Cookie Type***, then **conveyor #1** will continue moving (and deliver the tray onto conveyor #2).

ii. the **OVEN PRESET** is NOT configured for the ***Next Cookie Type***, then **conveyor #1** will **stop**, the **OVEN PRESET*** will be changed to the ***Next Cookie Type***, and then 2 seconds later, **conveyor #1** will **start moving forward** (and deliver the tray onto conveyor #2).

B) If **conveyor #2** contains the **same type** of tray as that at OD-3 (*Next Cookie Type*) and:

i. the **oven door** is **closed**, then **conveyor #1** will continue moving (the tray onto conv. #2).

ii. the **oven door** is already **open** (when the tray triggered OD-3), then **conveyor #1** will **stop** and **wait** for the **oven door to close**, after which **conveyor #1** will **start moving forward** (and deliver the tray onto conveyor #2).

C) If **conveyor #2** contains a **different type** of tray than that at OD-3 (*Next Cookie Type*), then **conveyor #1** will **stop** and wait until **conveyor #2** is completely **empty**, at which time the **OVEN PRESET*** will be changed to the ***Next Cookie Type***, and then 2 seconds later, **conveyor #1** will **start moving forward** (and deliver the tray onto conveyor #2).

***** – the **speed** of conveyor #2 must also change whenever the OVEN PRESET changes.

CONVEYOR #2 – Normal Operation

Once started (during SYSTEM STARTUP), **Conveyor #2** should operate continuously in the **forward direction** without stopping.

Additionally, the **speed** at which conveyor #2 operates is based on the *Cookie Type* (set by the **OVEN PRESET**) that the oven is configured to bake, and the speed **should not change** while any cookie trays are located on conveyor #2.

When a **tray breaks (triggers) OD-4**, the **oven door** will **OPEN**.

The **oven door** will (re)**CLOSE** **1 second** after **OD-4 clears**.

SHUTDOWN: [From "Normal Operation"]

During NORMAL OPERATION, **pressing and holding** the **STOP button** for at least **2 seconds** will cause the ***System Shutdown*** indicator to **illuminate**, the ***Normal Operation*** indicator to **shut OFF**, and the following set of ordered events to occur:

a) The **Safety Lights** will begin **flashing quickly** (**ON ½ sec ➡ OFF ½ sec ➡ repeat**).
b) The **Signal Horn** will **sound** (**ON**) for **3 seconds** (and then shut OFF).

Once step (**b**) is complete and **conveyor #1 is empty**:

c) Conveyor #1 will **stop**.
d) The **Signal Horn** will **sound** (**ON**) for **1 second** (and then shut OFF).

Once step (**d**) is complete and **conveyor #2 is empty**:

e) The **over door** will **OPEN,** and the **oven** will **de-energize**.
f) The **Signal Horn** will **sound** (**ON**) for **1 second** (and then shut OFF).

Once step (**f**) is complete, the **Safety Lights** will begin **flashing slowly** (**ON 1 sec ➡ OFF 1 sec ➡ repeat**) and the following set of ordered events will occur:

g) 6 seconds after the Safety Lights begin flashing slowly, **conveyor #2** will **stop**.
h) The **Signal Horn** will **sound** (**ON**) for **1 second** (and then shut OFF).
i) The **Safety Lights** will **stop flashing** (and will remain **OFF**) and the ***System Shutdown*** **indicator** will **shut OFF**.

When steps **a-i** are **complete**, the **system** is considered to be **fully de-energized** and should be able to either be re-started normally or reverse-started as described below:

REVERSE OPERATION: [from a fully de-energized state]

If the **system** is **fully de-energized**, **pressing and holding** the **REVERSE** button for at least **2 seconds** will cause both the ***System Starting*** and ***Reverse Operation*** **indicators** to **illuminate** and the following set of ordered events to occur:

a) The **Safety Lights** will begin **offset flashing** (**ON 1 sec ➡ OFF ½ sec ➡** repeat).
b) The **Safety Horn** will **sound** (**ON**) for **2 seconds ➡ shut OFF** for **½ second ➡ sound** (**ON**) again for **2 seconds ➡ shut OFF**.
c) When the **Signal Horn** finishes cycling **ON/OFF**, both **conveyors** will begin **moving** in **reverse**.

The **system** will **remain operating** in the reverse direction **until both conveyors** have been **empty** for **10 seconds**, at which time:

d) The **Safety Horn** will **sound** (**ON**) for **2 seconds** (and then shut OFF).
e) The **Safety Lights** will **stop flashing** (and will remain **OFF**)
f) The ***System Starting*** and ***Reverse Operation*** **indicators** will both turn **OFF**.

When steps **a-f** are **complete**, the **system** is considered to be **fully de-energized**.

Note – while in **REVERSE OPERATION**, pressing the **START** and/or **STOP** buttons will have no effect.

Improper Button Presses

Care should be taken to ensure that any improper button presses will **not** cause improper system operation. For example, the **REVERSE** button should have **no effect unless** the **system** is **fully de-energized**.

Notes Regarding the Optical Detectors and Trays Entering and Exiting the Conveyors

Optical detector **OD-1** is located at the beginning of conveyor #1 in order to **detect*** (**count**) the **trays entering** the conveyor. A **tray enters conveyor #1** when it **breaks OD-0** during forward operation.

Optical detector **OD-2** is located just before the end of conveyor #1 in order to **determine** the **type** of the next **cookie tray** that will be passed onto conveyor #2.

Optical detector **OD-3** is located at the end of conveyor #1 in order to **detect*** (**count**) the **trays** that are being transferred from conveyor #1 to conveyor #2. A **tray exits conveyor #1** when it **breaks and clears OD-3**, at which time it **enters conveyor #2** during forward operation.

Optical detector **OD-4** is located at the entrance of the oven in order to **trigger** the opening of the oven door due to an approaching tray during forward operation.

Optical detector **OD-5** is located at the end of the conveyor in order to **detect*** (**count**) the **trays exiting** the conveyor. A **tray exits conveyor #2** when it **breaks and clears OD-5**.

Once your logic for **SYSTEM STARTUP** is **fully functional**:

The logic for NORMAL OPERATION requires constant monitoring of the total number of trays located on conveyor #2 at any time. Optical detectors **OD-3** and **OD-5** can be used in conjunction with a **CTU** and **CTD** pair of instructions to perform this task.

Additionally, the logic for both SYSTEM SHUTDOWN and REVERSE OPERATION requires constant monitoring of the total number of trays located on conveyor #1. Optical detectors **OD-1** and **OD-3** can also be used in conjunction with another **CTU** and **CTD** pair of instructions to perform this task.

It is highly recommended that you create the logic required to perform these two tasks and make sure that logic is fully functional before you attempt to begin creating the logic specified previously for NORMAL OPERATION.