Interfacing Sepasoft Batch and Procedure Module with PLCs

Version History

Version Number	Revision Date	Revision Description	Change By	Additional Notes
0.1	01/09/2023	Draft	Tom Hechtman	
0.2	03/08/2023	Peer review update	Tom Hechtman	
0.3	03/29/2023	Added Ignition UDT information	Tom Hechtman	

This document provides an overview of interfacing the Sepasoft Batch & Procedure module with PLCs. The ISA-88 standard defined this interface at a high level, which the Sepasoft Batch & Procedure module follows. Rockwell Automation has extended this interface in their ControlLogix processors beyond the ISA-88 standard, and this document will discuss what is required in the ControlLogix processor to support interfacing to the Sepasoft Batch & Procedure module.

The basic interface used to pass data back and forth between a batch engine (in this case, the Sepasoft Batch & Procedure module) and a PLC is known as PLI (Phase Logic Interface). This is the default method unless the PLC supports an alternate method and it is selected to be used.

It is important to understand the nomenclature and concepts that are defined in the ISA-88 standard. Processes are broken down into granular tasks that are generically called phases. On the batch engine side, these are technically called Batch Phases, and on the PLC side, they are Equipment Phases.

There is a one-to-one mapping of these phases. For example, if there is an Add H2O batch phase defined in the batch engine, then there is a matching Add H2O equipment phase implemented in the PLC. When implementing an equipment phase in a PLC where extended functionality is not supported or selected to be used, standard logic is used to handle the execution of equipment phases.

The matching batch phase and equipment phase communicate using tags. The structure and definition of these tags are based on PLI. Many default parameters are defined in the ISA-88 standard, while others are included by Sepasoft for common helpful functionality. The user (typically the engineer) can add additional parameters specific to the phase. For example, a Mix Time parameter can be added to specify the duration of the mixing step.

The Sepasoft Batch & Procedure module will automatically create tags in the Ignition platform for the appropriate parameters defined for a batch phase. These tags can be mapped to OPC devices or Ignition reference tags that are passed to the PLC. The primary parameters, and associated tags, that control the execution and monitoring of equipment phases are the Command, Command_Number, State, and State_Number. The Command will have string values, such as Start and Stop, that are human-readable. The Command_Number will have a numeric value that is easier to handle in PLC logic.

There are several scenarios, and the following represents just the basic communication between the batch phase and the equipment phase during the execution of a batch recipe:

- System and user-defined parameter values defined in the recipe will be written to the tags by the batch engine. The PLC can read these values and are typically used in the equipment phase logic.
- The batch engine will set the Command to START and the Command_Number to 1.

- The batch engine will wait for the State to become Running. This is done when State_Number is set to 2 by the PLC.
- The Command will be set back to None, and the Command_Number set to 0.
- When the PLC has completed the phase, it will set the State_Number to 3 (Complete).
- The batch engine will set the Command to RESET and Command_Number to 7.
- The batch engine will wait until the PLC sets the State_Number to 1 (Idle).
- The phase is deactivated, and the batch continues with the next step.

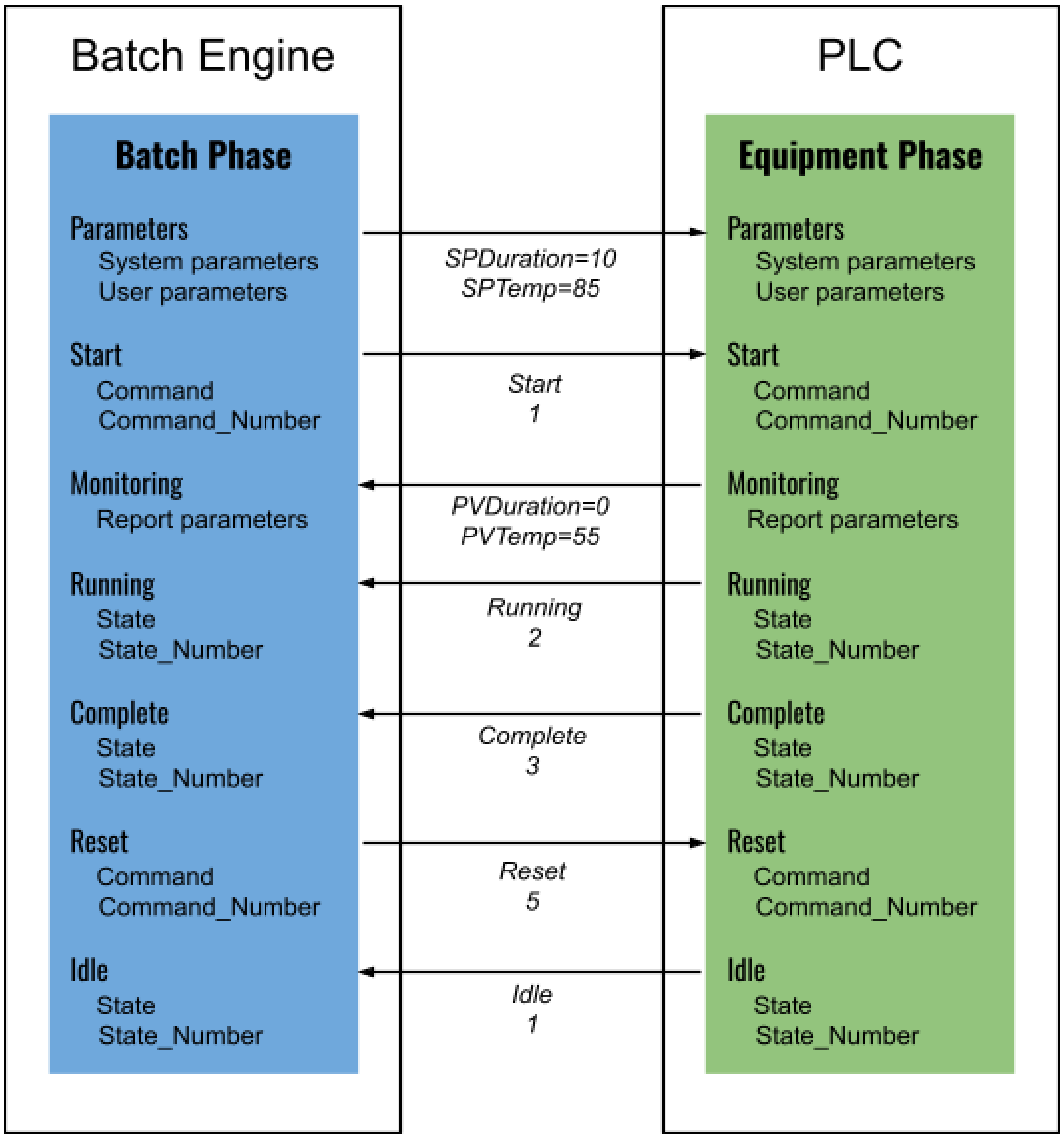


Figure 1: Batch Phase and Equipment Phase relationship

Commands and States

Because PLCs are better at detecting and setting numbers compared to text, the following integer values are used by the PLC to detect commands and set the states.

Command Name	Command Number
NONE	0
START	1
PAUSE	2
RESUME	3
HOLD	4
RESTART	5
STOP	6
RESET	7
ABORT	8

Table 1: Commands

State Name	State Number
IDLE	1
RUNNING	2
COMPLETE	3
RESTARTING	4
RESETTING	5
PAUSING	6
PAUSED	7
HOLDING	8
HELD	9
STOPPING	10
STOPPED	11
ABORTING	12
ABORTED	13

Table 2: States

State Diagram

The following diagram shows the appropriate commands for all of the states. The states are shown in boxes, and the commands are on the lines between the states. The appropriate command depends on the current state. For example, in Idle (green box on the left), the only appropriate command is Start which will change the state to Running.

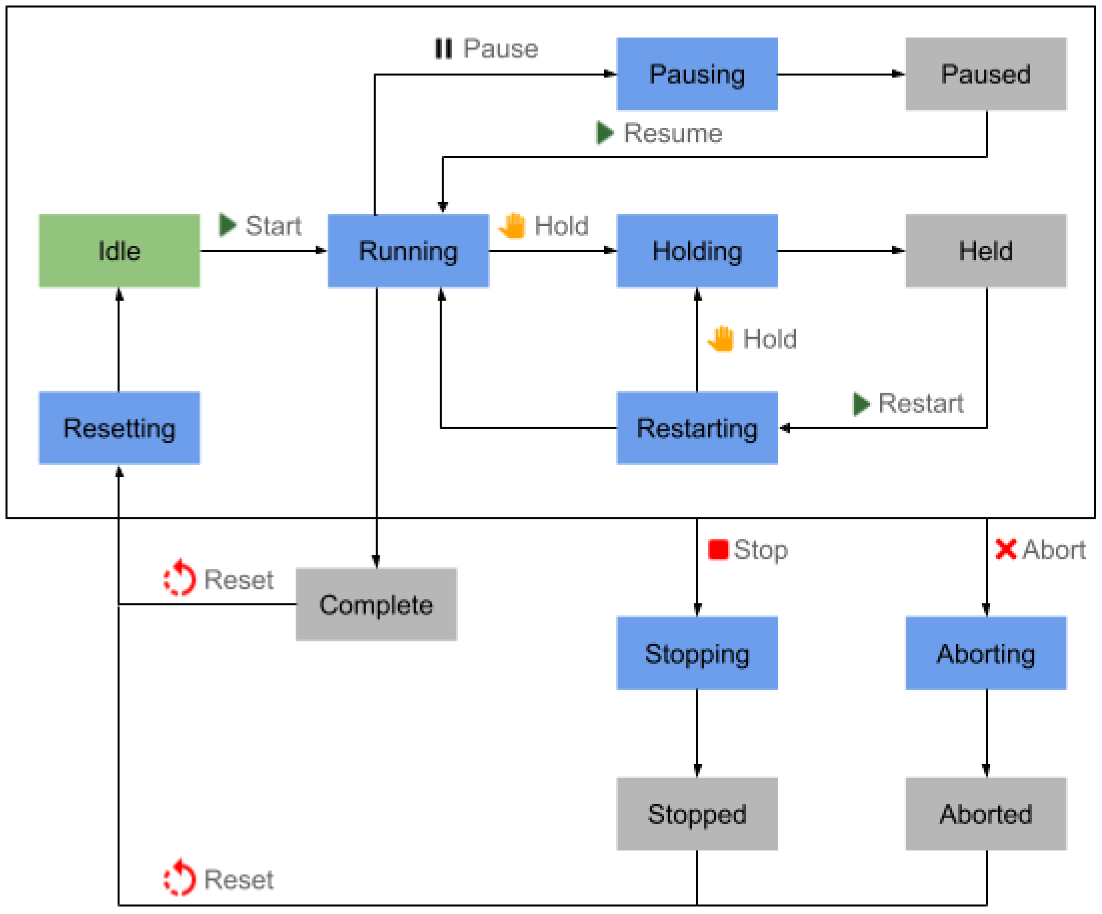


Figure 2: State diagram

Current State	Command								New Final State
	Start	Stop	Hold	Restart	Abort	Reset	Pause	Resume	
Idle	Running								
Running		Stopping	Holding		Aborting		Pausing		Complete
Complete						Resetting			
Pausing		Stopping	Holding		Aborting				Paused
Paused		Stopping	Holding		Aborting			Running	
Holding		Stopping		Restarting	Aborting				Held
Held		Stopping			Aborting				
Restarting		Stopping	Holding		Aborting				Running
Stopping					Aborting				Stopped
Stopped					Aborting	Resetting			
Aborting									Aborted
Aborted						Resetting			
Resetting									Idle

Table 3: Command and state transition table

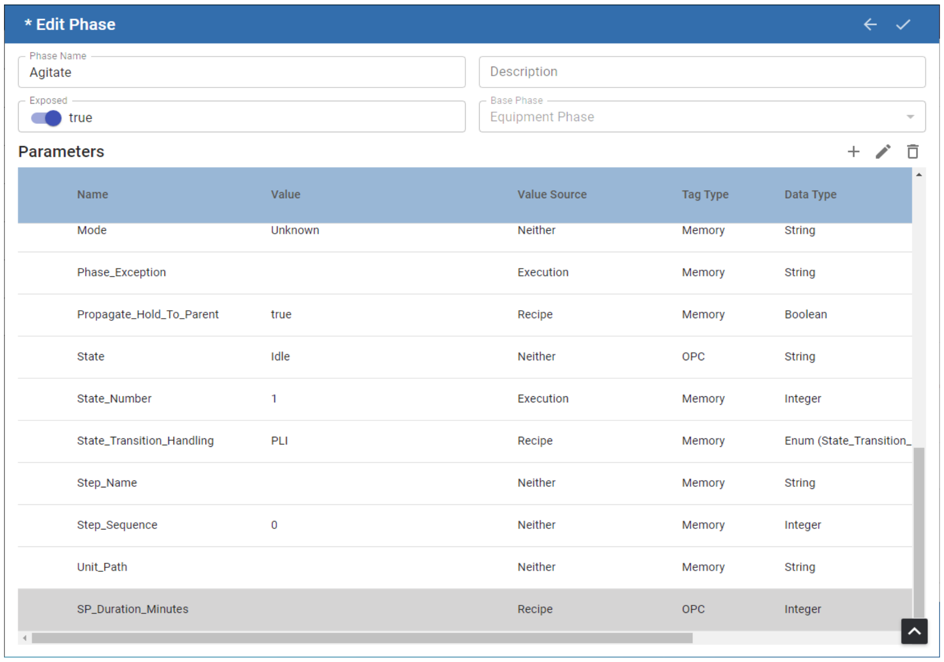
In the event that communications are lost or a restart of the batch engine, the batch engine will adapt to the current state read from the PLC. In the scenario that communications are lost between the two and the PLC continues the phase to completion, the following will occur when communications are reestablished:

1. For safety reasons, when the batch engine starts, all running batches are HELD
2. The batch is RESTARTED by the user or from a script
3. Each phase state is read from the PLC
4. If the state is:
    a. RUNNING, then the phase will continue to run
    b. COMPLETE, then the phase will be considered complete, and a RESET command will be issued
    c. HELD or HOLDING, then the phase will remain held until a RESTART command is issued by the user or scripting
    d. PAUSED or PAUSING, then the phase will remain paused until a RESUME command is issued by the user or scripting
    e. STOPPED or STOPPING, then the phase will remain stopped until a RESET command is issued by the user or scripting
    f. ABORTED or ABORTING, then the phase will remain aborted until a RESET command is issued by the user or scripting

Ignition UDTs

On the Sepasoft Batch and Procedure module end, Phases are managed using the Phase Manager component or by using scripting. When the Exposed option is set to True as shown in figure 3, a UDT (User Defined Type) for the Agitate phase is automatically created in Ignition. The UDT will include a member for each system and user-defined parameter. The Tag Type setting, as shown in figure 4, will determine the type of UDT member that can be one of the following.

- Memory - simple tags that do not poll or update their values. These can be bound to in Ignition Perspective views, access in scripting, etc.
- OPC - tags that are linked to field devices (typically PLCs) through an OPC server.
- Reference - tags that refer to other existing tags. This type can be used for linking to MQTT tags.



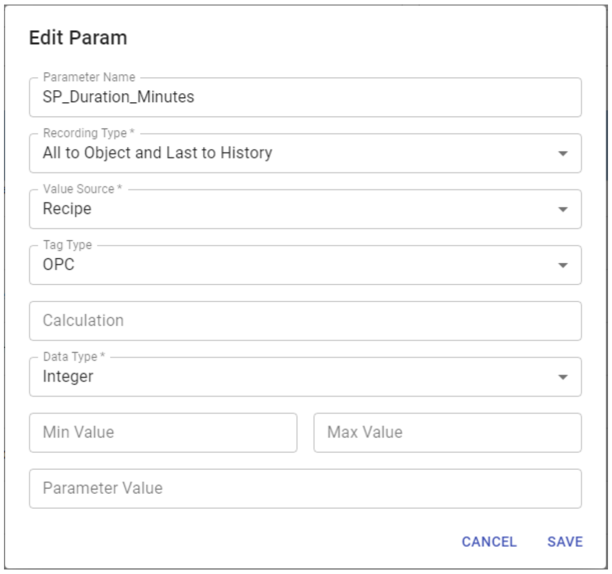
Phase Name	Agitate
Description	
Exposed	true
Base Phase	Equipment Phase

Parameters

Name	Value	Value Source	Tag Type	Data Type
Mode	Unknown	Neither	Memory	String
Phase_Exception		Execution	Memory	String
Propagate_Hold_To_Parent	true	Recipe	Memory	Boolean
State	Idle	Neither	OPC	String
State_Number	1	Execution	Memory	Integer
State_Transition_Handling	PLI	Recipe	Memory	Enum (State_Transition_
Step_Name		Neither	Memory	String
Step_Sequence	0	Neither	Memory	Integer
Unit_Path		Neither	Memory	String
SP_Duration_Minutes		Recipe	OPC	Integer

Figure 3: Batch and Procedure phase with the Expose option selected.

The SP_Duration_Minutes duration parameter is set to OPC tag type and a Data Type of Integer, as shown in figure 4. Note that many PLC vendors do not support spaces in the tag names, and for this reason, underscores should be used instead.


Edit Param

Parameter Name: SP_Duration_Minutes

Recording Type *: All to Object and Last to History

Value Source *: Recipe

Tag Type: OPC

Calculation

Data Type *: Integer

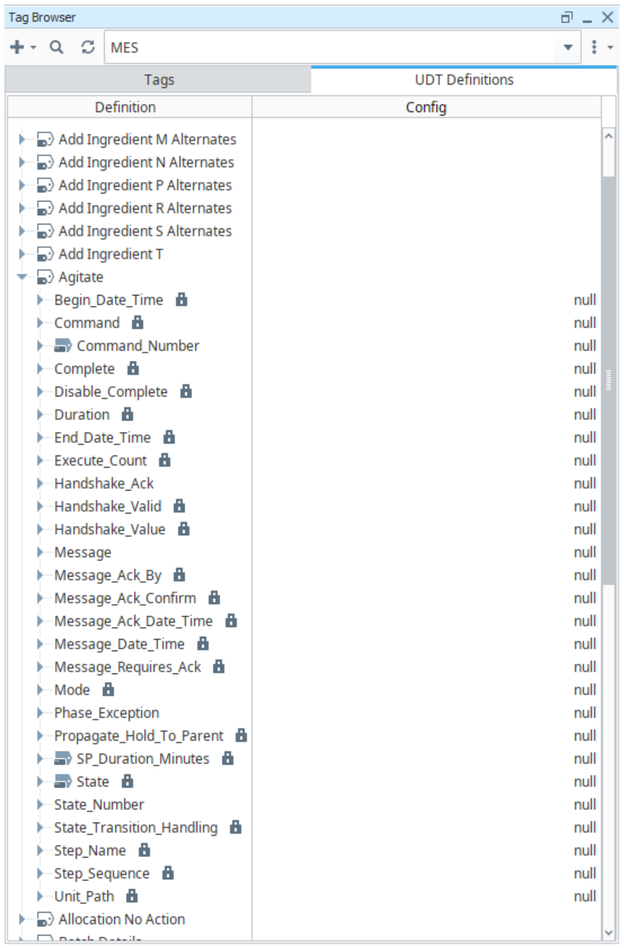
Min Value

Max Value

Parameter Value

Figure 4: Batch parameter setting, including the tag type.

When the phase configuration is saved, the Agitate UDT will be automatically created in the MES tag provider. Refer to Figure 5 and note that the SP_Duration_Minutes member of the UDT has a lock next to the name. This is because the parameter Value Source is set to Recipe. This means the value can only be set in the master recipe and not changed thereafter. If the Value Source is set to Recipe and Execution, the lock will not appear, and the value can be changed during execution originating from within the batch engine or PLC.

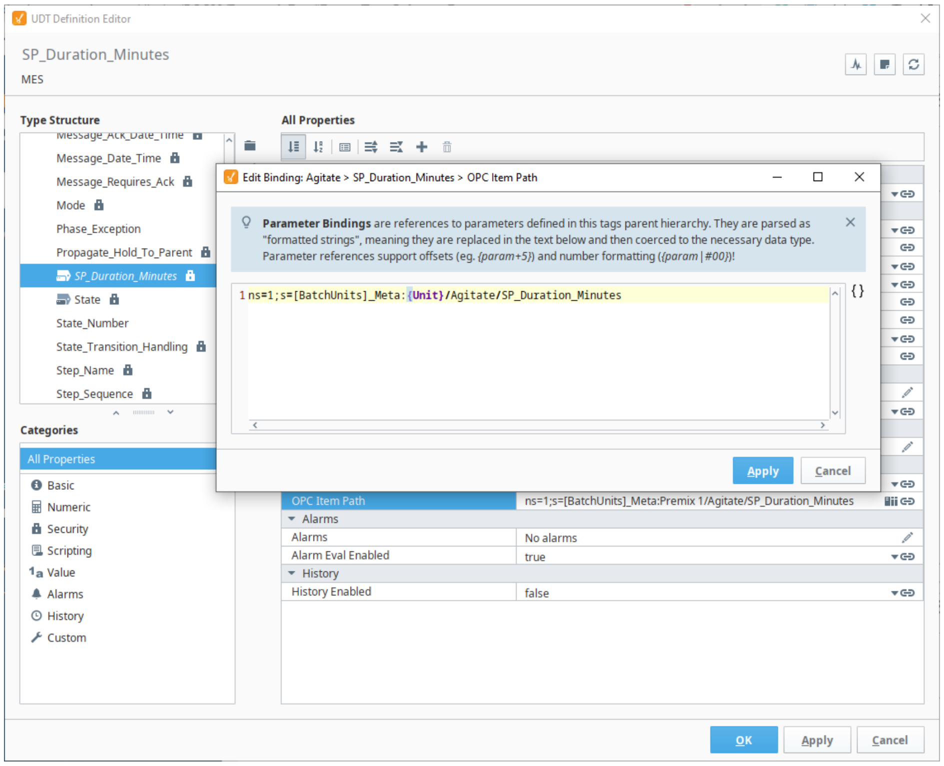


Definition	Config
Add Ingredient M Alternates	
Add Ingredient N Alternates	
Add Ingredient P Alternates	
Add Ingredient R Alternates	
Add Ingredient S Alternates	
Add Ingredient T	
Agitate	
Begin_Date_Time	null
Command	null
Command_Number	null
Complete	null
Disable_Complete	null
Duration	null
End_Date_Time	null
Execute_Count	null
Handshake_Ack	null
Handshake_Valid	null
Handshake_Value	null
Message	null
Message_Ack_By	null
Message_Ack_Confirm	null
Message_Ack_Date_Time	null
Message_Date_Time	null
Message_Requires_Ack	null
Mode	null
Phase_Exception	null
Propagate_Hold_To_Parent	null
SP_Duration_Minutes	null
State	null
State_Number	null
State_Transition_Handling	null
Step_Name	null
Step_Sequence	null
Unit_Path	null
Allocation No Action	

Figure 5: Tag Browser in the Ignition Designer showing the Agitate UDT

The UDT can be edited to assign the OPC item paths or reference tag paths. Both can be parameterized to allow dynamic paths based on the unit name or other UDT parameter values. As shown in figure 6, the `{Unit}` portion of the OPC Item Path will be replaced with the unit name configured in the Batch and Procedure module for all instances of the UDT.

When scaling to multiple units that support the same phases, the use of parameterized OPC Item Paths will eliminate manually mapping them. This structure should be used for greenfield implementations. For an existing implementation that does not have a good structure, manually assigning the OPC Item Paths in the instance must be done.



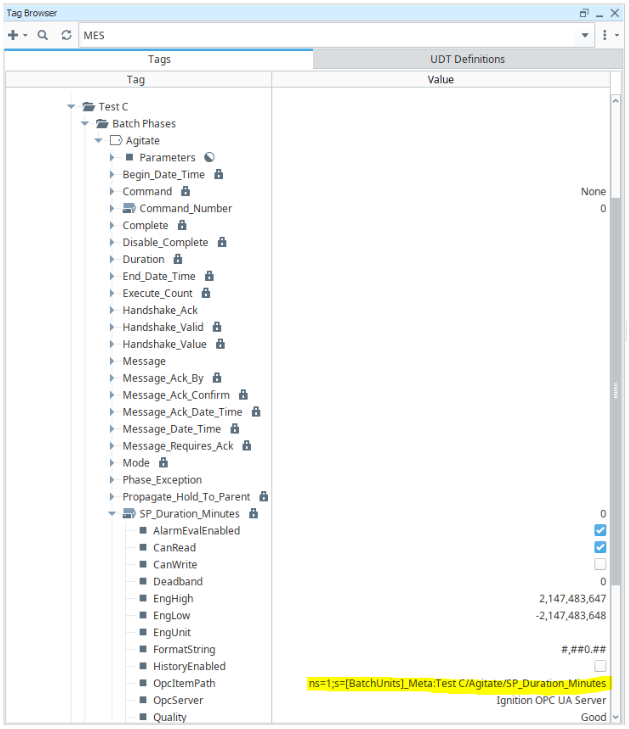
Parameter Bindings are references to parameters defined in this tags parent hierarchy. They are parsed as "formatted strings", meaning they are replaced in the text below and then coerced to the necessary data type. Parameter references support offsets (eg. *{param+5}*) and number formatting (*{param|#00}*)!

```
ns=1;s=[BatchUnits]_Meta:{Unit}/Agitate/SP_Duration_Minutes
```

OPC Item Path	ns=1;s=[BatchUnits]_Meta:Premix 1/Agitate/SP_Duration_Minutes
Alarms	
Alarms	No alarms
Alarm Eval Enabled	true
History	
History Enabled	false

Figure 6: UDT Editor in the Ignition Designer showing an OPC Item Path

Once the UDT is configured, an instance of it will be created for each unit that is configured for the associated phase. Note in figure 7 that the `{Unit}` UDT parameter of OPC Item Path has been replaced with `Test C`.



Tag Browser

MES

Tags | UDT Definitions

Tag	Value
Test C	
Batch Phases	
Agitate	
Parameters	
Begin_Date_Time	
Command	None
Command_Number	0
Complete	
Disable_Complete	
Duration	
End_Date_Time	
Execute_Count	
Handshake_Ack	
Handshake_Valid	
Handshake_Value	
Message	
Message_Ack_By	
Message_Ack_Confirm	
Message_Ack_Date_Time	
Message_Date_Time	
Message_Requires_Ack	
Mode	
Phase_Exception	
Propagate_Hold_To_Parent	
SP_Duration_Minutes	0
AlarmEvalEnabled	☑
CanRead	☑
CanWrite	☐
Deadband	0
EngHigh	2,147,483,647
EngLow	-2,147,483,648
EngUnit	
FormatString	#,##0.##
HistoryEnabled	☐
OpcItemPath	ns=1;s=[BatchUnits]_Meta:Test C/Agitate/SP_Duration_Minutes
OpcServer	Ignition OPC UA Server
Quality	Good

Figure 7: UDT Editor in the Ignition Designer showing an OPC Item Path

Handshaking

The batch engine generates a new sequential handshake value every second that can be used to verify communications between the batch engine and the PLC. Referring to Figure 8, if the PLC doesn't detect the Handshake_Value tag value changing every second, it can respond appropriately to the loss of communications to maintain safety. In the batch engine, the Handshake_Valid parameter or tag can be used to handle lost communications.

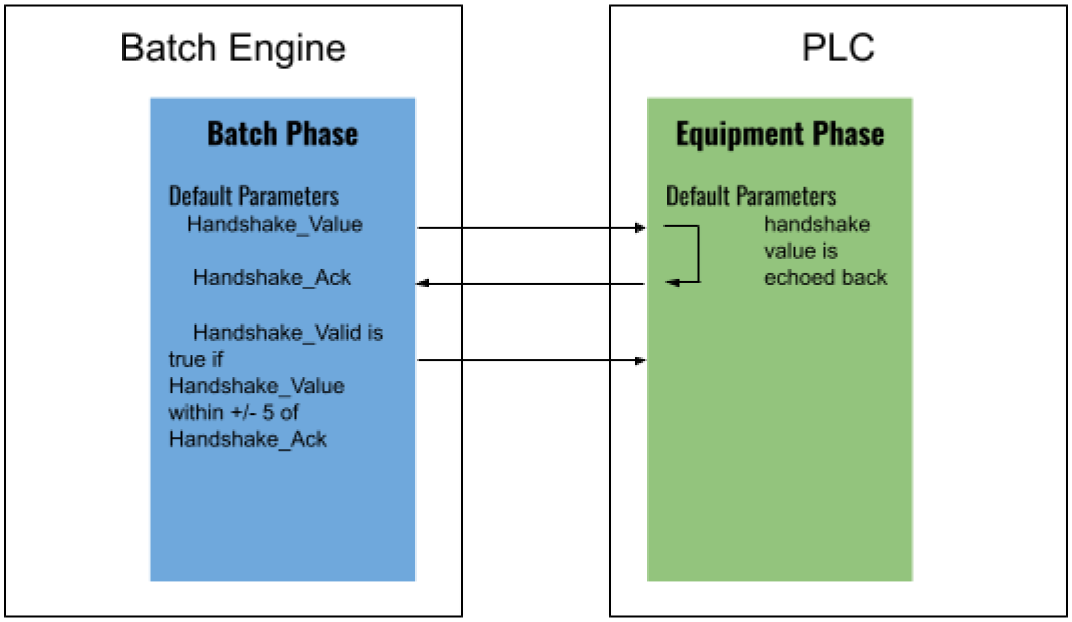


Figure 8: Handshake relationship between batch engine and PLC

ControlLogix Processors

ControlLogix processors from Rockwell Automation support extended equipment phase functionality by enabling the CIP Phase Manager. This is optional, and if it is not enabled, the functionality described above can be used. If it is being used, phase instructions and separate program logic files are used for each state. Going back to our Add H2O example, when a phase transitions to the Running state, a program file contains logic to control the valves, pumps, monitor the amount added, handle safety, and handle exceptions. There is a separate program file for the Resetting state that can handle items like zeroing the flow meter, etc.

Because the CIP Phase Manager doesn't use tags, there is a program file specific to handling the PLI interface. This will need logic to monitor the Command_Number tag and execute a PLC instruction against the equipment phase. For example, when the Command_Number = 1, it executes the Phase Start command. And when the Running bit on the Equipment Phase is detected, it writes 2 into the State_Number tag.

PLI Logic

The following diagram shows an example of a Unit (MashKettle2) folder followed by a phase folder (MK_Phase) which contains all the equipment phases with all the state's subroutines. All the logic, conditions, and commands will be programmed under the "Running" subroutine.

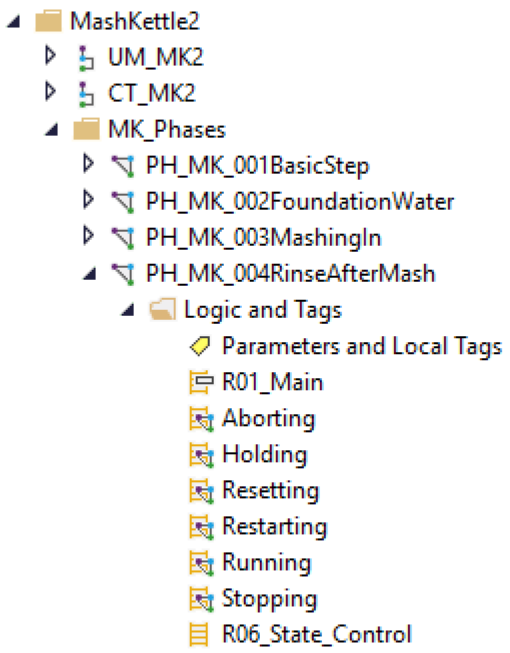
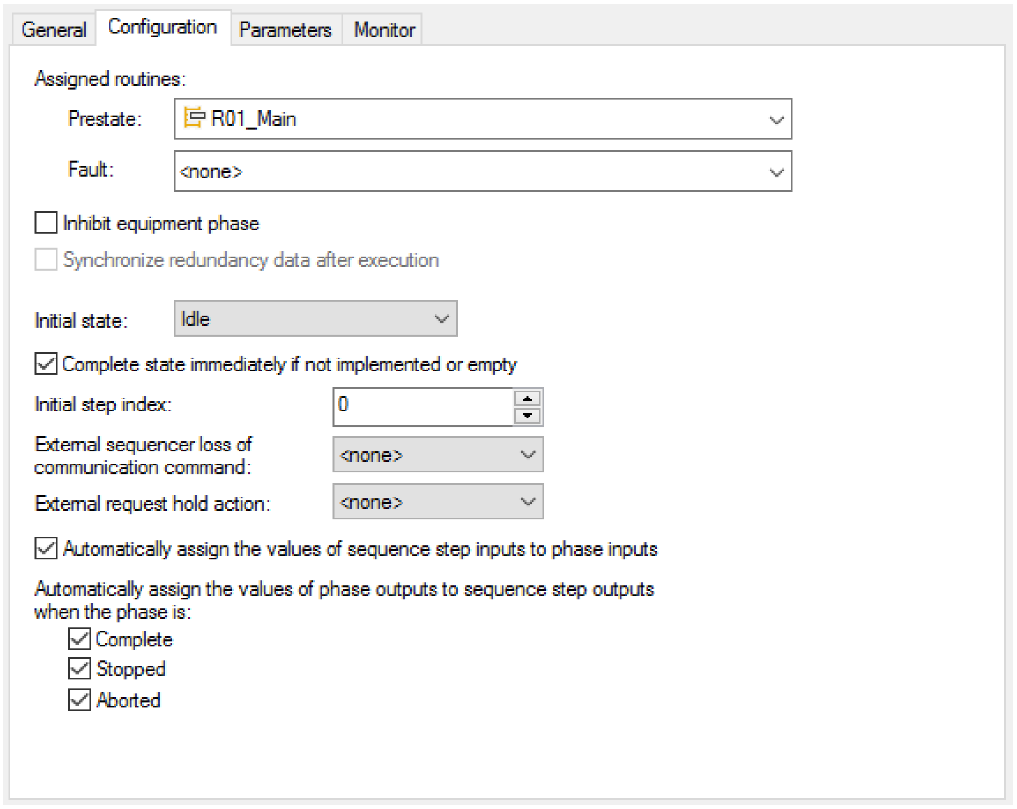


Figure 9: Phase routine structure in ControlLogix logical organizer

Figure 10 shows an example of an equipment phase's options and configurations



Assigned routines:

Prestate: R01_Main

Fault: <none>

☐ Inhibit equipment phase

☐ Synchronize redundancy data after execution

Initial state: Idle

☑ Complete state immediately if not implemented or empty

Initial step index: 0

External sequencer loss of communication command: <none>

External request hold action: <none>

☑ Automatically assign the values of sequence step inputs to phase inputs

Automatically assign the values of phase outputs to sequence step outputs when the phase is:

☑ Complete

☑ Stopped

☑ Aborted

Figure 10: Phase routine structure in ControlLogix logical organizer

Command Control Logic

Figure 11 shows an example of equipment phase command logic to interface the command value received from the batch engine and execute the appropriate PLC instruction. Command _Number holds the command value from the batch engine as an integer value and executes the appropriate command on the equipment phase via the "PCMD" PLC instruction.

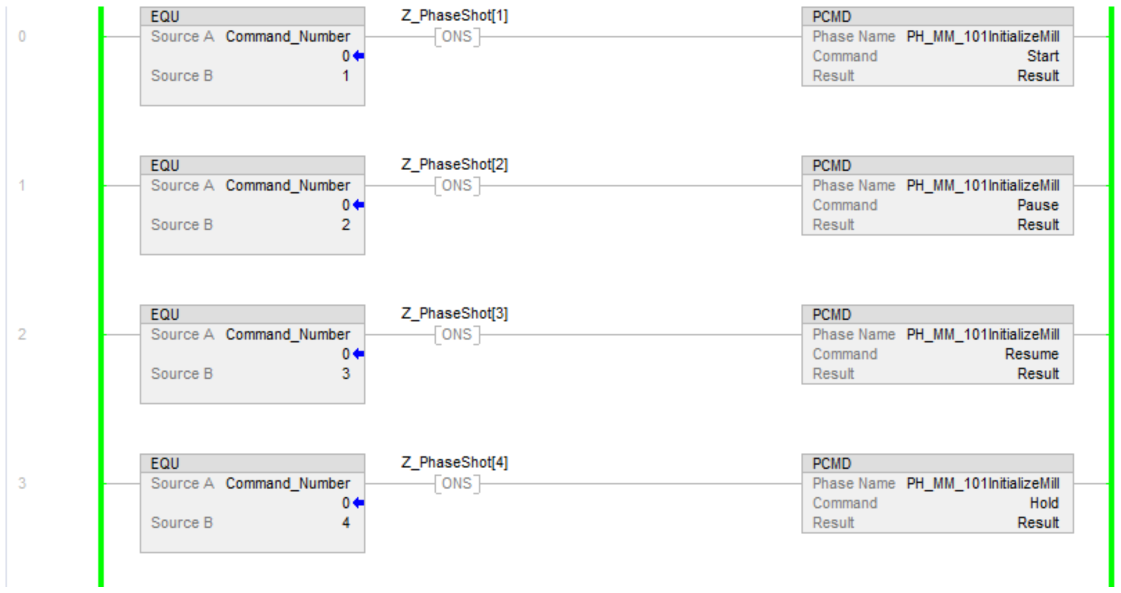
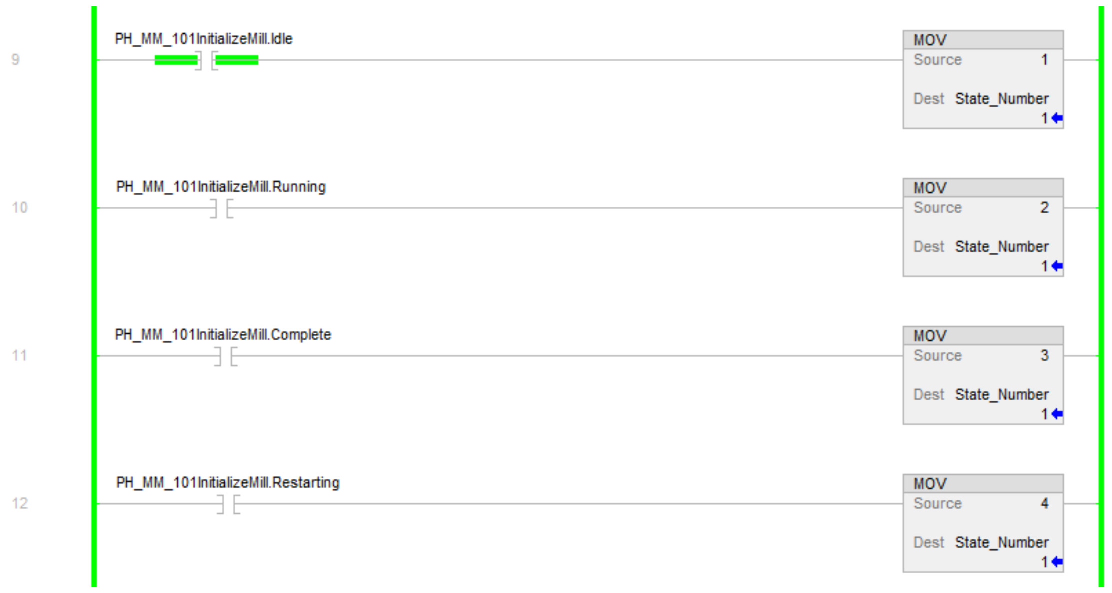


Figure 11: ControlLogix command logic

State Control Logic

Figure 12 shows an example of equipment phase state logic to interface echoing the state from the PLC to the batch engine. Equipment phase tags in the PLC represent the state of a phase as a boolean value and then set the corresponding state number tag (State_Number) as an integer used by the batch engine. This is accomplished with the “MOV” PLC instruction.



9
PH_MM_101InitializeMill.Idle
MOV
Source 1
Dest State_Number
1
10
PH_MM_101InitializeMill.Running
MOV
Source 2
Dest State_Number
1
11
PH_MM_101InitializeMill.Complete
MOV
Source 3
Dest State_Number
1
12
PH_MM_101InitializeMill.Restarting
MOV
Source 4
Dest State_Number
1

Figure 12: ControlLogix state logic

Batch Message Control Logic

Figure 13 shows an example of equipment phase message logic from the PLC to the Batch engine. When the “TimerMonitor.Out_Reached” tag activates, it will modify the “Message” tag of the batch engine, which is a string value. This modification of string value will initiate a Batch message on the HMI side if the step is in the “Running” state.
Then if the “TimerMonitor.Out_Reached” tag deactivates or the “Message_Ack_Confirm” tag from the Batch engine activates, then the “Null” value will be moved to the “Message” string tag, which clears the Batch message on the batch engine side.

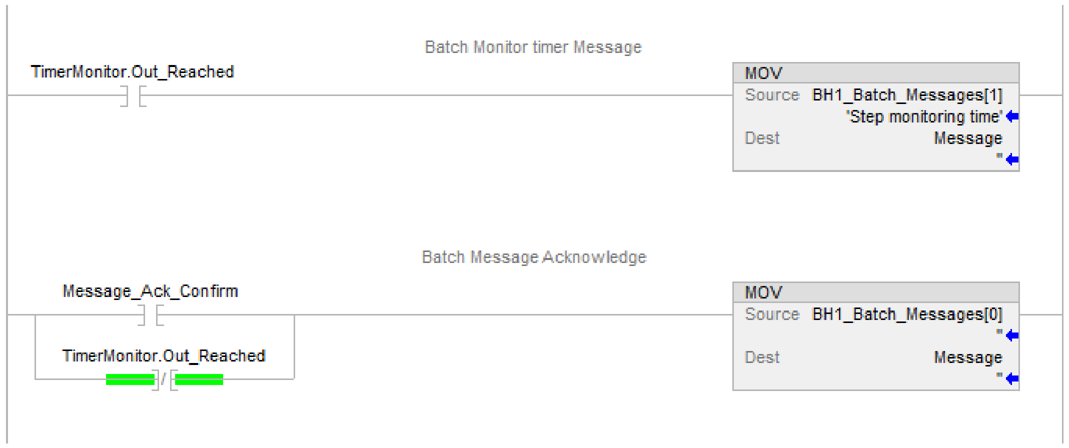


Figure 13: PLC-generated message logic