A REVIEW OF AUTOMATIC COMPRESSOR CONTROL USING PROGRAMMABLE LOGIC CONTROLLER

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Abstract – *The need to move gases has been a requirement of industry since Iron age. As with any fluid, gases move from a higher pressure to lower pressure in virtually all systems. For that movement of gases, there must be a means of producing driving force, which is the higher pressure. The equipment that raises gas to a higher pressure is called a compressor. Compressed air system controls are one of the most important determinants of overall system energy efficiency because they match compressed air supply with system demand. Control is critical to the efficient operation and high performance of a system. The compressor control can be automated by adding PLC to the interlock system of a compressor. This will increase the safety limit and avoid the unwanted shutting down of plant. A Programmable Logic Controller (PLC) is a preprogrammed, ruggedized, digital industrial computer control system that performs automatic tasks in industrial processes. To perform the work in the industrial process or machinery, the PLC continuously monitors and receives information from input devices or sensors, processes the information, and triggers the connected output devices. This paper outlines the review of compressor interlocking using PLC.*

***Key Words*: Programmable Logic Controller, Ladder Diagram Logic, Compressor, Rotary Compressor, Centrifugal compressor, Interlocking, Surge protection, etc.**

1.INTRODUCTION

Most people do not think much about compressed air as they go about their daily lives, even though it is all around them. Indeed, the importance of compressed air and industrial compressors in the global economy cannot be overstated. Compressed air, which is used in almost every industry, is widely regarded as the fourth utility, alongside water, electricity, and natural gas. Industrial compressors are just as important today as steam engines were during the industrial revolution. Most manufacturing plants around the world would shut down if they did not have them. After all, compressed air accounts for roughly one-third of the energy consumed by a typical factory. However, compressed air is not only required in manufacturing facilities. It is also required for the operation of ships, trains, and automobiles, for example, as a critical component of the brake system, suspension, and to ensure that airbags deploy in the event of an accident. Furthermore, compressed air is used by a wide range of professionals, including car mechanics and dentists.

Monitoring and controlling compressed air system can have a significant impact on day-to-day operations and overall performance. Compressor operation can be automated by connecting PLC to the network. This will enhance the safety limit and can avoid undesirable shut down. PLC-based systems will be an excellent alternative for automating a process system and minimizing human intervention. They will monitor the system and aid to reduce human error. PLC's widespread use in a variety of fields has made a substantial contribution to the operation and automatic control of electrical and electronic systems.

1.1 PROGRAMMABLE LOGIC CONTROLLER

Programmable Logic Controllers (PLC's) are small industrial computers with modular components designed to automate customized control processes. PLC's are often used in factories and industrial plants to control motors, pumps, lights, fans, circuit breakers and other machinery.

1.1.1. BLOCK DIAGRAM OF PLC

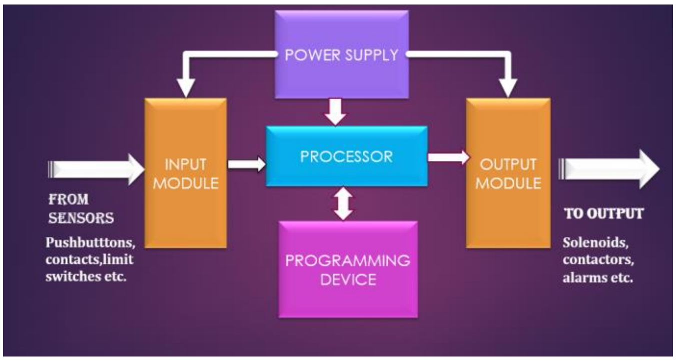

Fig-1: Block diagram of PLC

The main parts of PLC are Input Module, Processor, Output Module, Power Supply and Programming Device. Processor or Central Processing Unit is the heart of the PLC. It is a micro-controller-based circuitry. The CPU consists of Arithmetic Logic Unit (ALU), Program memory, Internal timers, and controllers. CPU performs the task necessary to fulfill the PLC functions. These tasks include scanning, I/O traffic control, program execution, peripheral and external device communication, special functions or data handling execution and self-diagnostics.

Input module acts as an interface between real time status of process variable and the CPU. This module accepts and converts signals from sensors into logic signal.

Table-1: Examples of Input module

Analog Input module	Digital input module
Pressure, Flow, Level Tx, RTD(Ohm), Thermocouple (mV)	Switches, Pushbuttons, Relays, Pump valve on off status.

Output module act as link between the CPU and the output of the field. This module converts control instructions into signal that can be used by actuators.

Table-1: Examples of Output module

Analog output module	Digital output module.
Control valve, speed, vibration	Solenoid valves, Lamps, Actuators, dampers, Pump valve on off control.

The power supply gives the voltage required for electronics module (I/O logic signals, CPU, memory unit and peripheral devices) of the PLC from the line supply. The power supply provides isolation necessary to protect solid state devices from most high voltage line spikes. As I/O is expanded, some PLC may require additional power supplies to main proper power levels.

The bus system is a signal transmission path. This system oversees signal exchange between the processor and the I/O modules. It is made up of several single-line wires and tracks. The operating cycle of PLC is shown in the below figure.

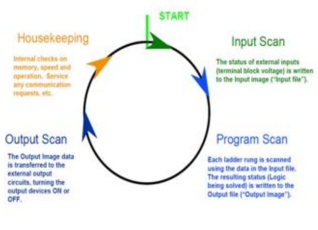

Fig-2: PLC operating cycle

PLC operations of four steps. They are as follows

1. Input Scan -Examine the status of input.
2. Program Scan- executes the program logic
3. Output Scan-Enable/Disable the outputs
4. Housekeeping- entails communication, internal diagnostics, and so on.

These steps are processed in a loop and repeated continuously. The signal flow in the PLC is shown in the below figure.

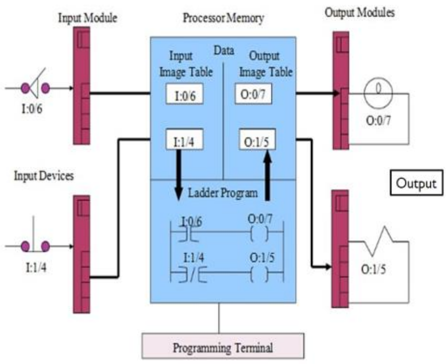

Fig-3: PLC signal flow

The user tracks control tasks in a program. The program for specific tasks is created using a set of language elements. Because tasks for binary signal processing are being handled, the language elements for these functions are being interrupted. Five programming languages have been developed for practical use based on such limited requirements. They are Ladder Diagram (LD), Function Block (FBD), Structured Text (ST), Instruction List (IL), and Sequential Function Chart (SFC).

Ladder Diagram (LD), also known as Ladder Logic, is the first IEC 61131-3 language. It is the most widely used PLC language because it was designed to replace hardwired relay control systems. Ladder Diagram employs internal logic to replace all but the physical devices that require an electrical signal to be activated. Ladder Diagram is built in the form of horizontal rungs with two vertical rails that represent the electrical connection on relay-logic schematics.

Function Block Diagram is the second most popular PLC programming language (FBD). The Function Block Diagram is a graphical language. The Function Block Diagram depicts a function between inputs and outputs that are connected by connection lines in blocks.

Structured Text is the third PLC Programming Language. This language is a textual based language. Structured Text is a high-level programming language like Basic, Pascal, and "C." It is a very powerful tool capable of performing complex tasks involving algorithms and mathematical functions, as well as repetitive tasks. Statements are separated by semicolons in the code, and these statements change inputs, outputs, or variables.

The Instruction List is also a textual based language. Assembly Language is like the Instruction List language. You will use *mnemonic* codes such as LD (Load), AND, OR, and so on when using this PLC Programming Language. The Instruction List contains instructions, each on a new line, with any comments you want to add at the end of each line.

SFCs are a graphical programming language, not text based. A step is basically some function within the overall system, like an individual machine process. A transition is just that, the change from one step to another step or state. Beyond the basics, SFC programs can also include standard logical programming techniques such as

feedback loops and branching (either parallel or alternative branches.) SFCs can also be designed with the aid of state diagrams.
In this paper, Ladder Logic programming language is used for the automatic compressor control.

2. COMPRESSOR

Compressors are mechanical devices that elevate the pressure of compressible fluids or gases, the most common of which being air. Compressors are used in a variety of industries to supply shop or instrument air, power air tools, paint sprayers, and abrasive blast equipment, phase shift refrigerants for air conditioning and refrigeration, and drive gas through pipelines, among other things. At the compressor, the low-pressure gas is changed to high pressure gas.

2.1 TYPES OF COMPRESSORS

The compressor may be classified as:

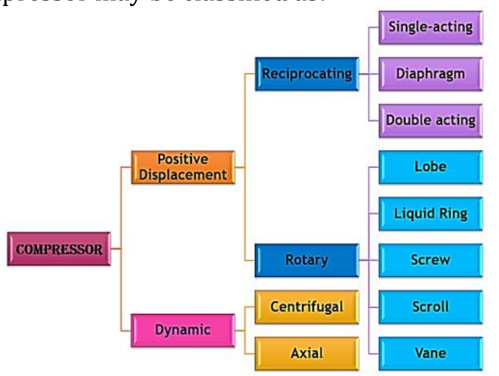

Fig-4: Classification of Compressors

2.1.1. ROTARY COMPRESSOR

A rotary compressor operates by confining a volume of gas in a packet formed by two rotating components. As these components continue their rotation, the volume of pocket is decreased.

2.1.2 CENTRIFUGAL COMPRESSOR

A centrifugal compressor increases the pressure of a gas by first accelerating the gas then converting the energy of the gas velocity (kinetic energy) into pressure (potential energy). The gas is accelerated a rotating impeller or wheel.

A centrifugal blower compressor consists of a rotor to which several curved vanes are fitted symmetrically. The rotor rotates in an airtight volute casing with inlet and outlet points. The casing is so designed that the kinetic energy is converted to pressure energy. The mechanical energy is provided to the rotor from some external source. As the rotor rotates it sucks air thru it eyes, increases the pressure due to centrifugal force and forces the air to flow over the diffuser. Finally, the pressured air is delivered to the receiver. Centrifugal compressors are widely used in plant air package systems.

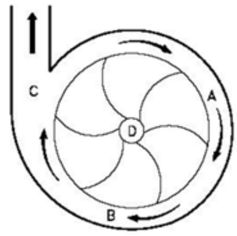

Fig-5: Centrifugal Compressor

The centrifugal compressor, originally built to handle only large volumes of low-pressure gas and air (maximum of 40 PSIG), has been developed to enable it to move large volumes of gas with discharge pressure up to 3500 psig. However, centrifugal compressors are now most frequently used for medium volume and medium pressure air delivery. One advantage of a centrifugal pump is the smooth discharge of the compressed air.

The centrifugal force utilized by the compressor is the same force utilized by the centrifugal pump. The air particles enter the eye of the impeller. As the impeller rotates, air is thrown against the casing of the compressor. The air becomes compressed as more and more air are thrown out to the casing by the impelling blades. The air is pushed along the path designated A, B and C in the below figure. The pressure of the air is increased as it is pushed along this path. Note in figure that the impeller blades curve forward, which is opposite to the backward curve used in typical centrifugal liquid pumps. Centrifugal compressors use variety of blades orientation including both forward and backward curves as well as other designs.

There may be several stages to a centrifugal air compressor, as in the centrifugal pumps, and the result would be the same, a higher pressure would be produced. The air compressor is used to create compressed or higher pressure would be produced. The air compressor is used to create compressed or higher-pressure air for a variety of uses. Some of its uses are pneumatics control devices, pneumatic sensors, pneumatic motor and starting air for diesel engines.

The plant air package system (PAP) consists of three stage centrifugal compressor with various accessories. The first and second stage impellers are mounted at opposite ends of the low-speed pinion and the third stage impeller is mounted on high-speed pinion. The impellers are placed in a scroll type casing.

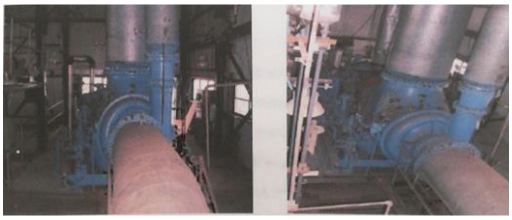

Fig-6: Side views of Compressor

The pinion is driven by one gear. Horizontal split carbon-labyrinth seal assemblies prevent air leakage along the pinion shaft into the gear case. The atmosphere air is sucked into the first stage through a filter and inlet control valve. The compressed air from the third stage is discharged into an air chamber and an unloading valve is provided to control the discharge pressure.

The control system automatically positions inlet control valve in accordance with inlet air temperature and pressure, to provide the compressor with air at constant density. Protecting devices automatically shut down the compressor in the event of high air temperature, high oil temperature, low oil, or high rotor vibration.

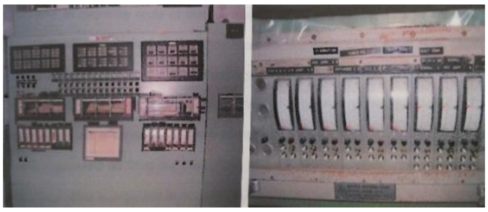

Fig-7: Control panel of Air compressor

2.2 COMPRESSOR COOLERS.

The amount of moisture that can hold is inversely proportional to the pressure of the air. As the pressure of the air increases, the amount of moisture that can hold decreases. The amount of moisture that can air hold is also proportional to the temperature of the air. As the temperature of air increases, the amount of moisture increases. However, the pressure change of the compressed air is larger than the temperature change of the compressed air. This causes moisture in the air to condense. Moisture in the compressed air systems can cause serious damage. The condensed moisture can cause corrosion, water hammers and freeze damage, therefore, it is important to avoid moisture in compressed air systems. The coolers are used to minimize the problems caused by heat and moisture in the compressed air systems.

2.2.1CENTRIFUGAL COMPRESSOR SURGE CONTROLLED.

Compressor surge is a condition affecting both aerospace and industrial compression system that employs turbo machinery. Surge is an unstable operating condition that can lead to the loss of an aircraft in aerospace applications and cause severe damage to industrial systems. Most compressors have a stability limit that is defined by a minimum flow rate on a pressure-rise vs flow-rate characteristic curve.

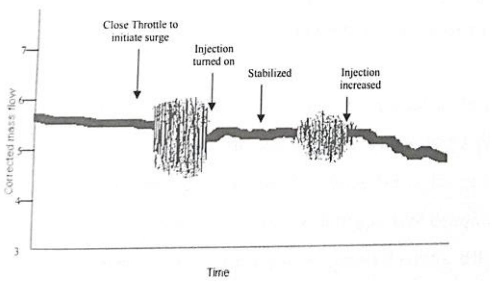

Fig-8: Graphical representation of compressor surge

Surge margin refers to a margin of safety between the normal operating point of the compressor and the stability limit. Events, both external and internal to the compression system, will occasionally move compressor operating to a point that is beyond its stability limit, causing a surge condition. Technology that increases the stable operating range of the compressor or provides a means to recover from surge will improve the safety and performance of turbo machinery-based compression systems.

Air injection has been demonstrated to improve centrifugal compressor stability at the NASA Glenn Research Center. In the earlier work, air was injected through the hub surface of the vaned diffuser in a 4:1 pressure ration centrifugal compressor to provide a 14% improvement in surge margin. Currently, the technology has been applied to the shroud surface to the diffuser and greater improvements have been achieved. The ability to recover from surge has also been demonstrated.

Air was injected into the diffuser through the shroud surface of the path between the impeller training edge and the leading edge of the diffuser vanes. Eight injector nozzles were positioned quasi-uniformly about the circumference of the diffuser. The nozzle flow path and discharge path were designed to produce a jet that remained attached to the surface as it traveled into the diffuser passage. Several orientations of the injected air steam and variations in the number of active nozzles were tested. Range improvements were demonstrated both when an external source was used for the injected air and when an internal source was used that took injection air from the compressor flow path.

2.2.2. SURGE PROTECTION

The surge protection system consists of a differential pressure switch and a needle valve (NV2). SUPS is electrically to the solenoid valve UVS. SUPS is electrically connected to solenoid valve UVS which directs air signal to the unloading valve actuator during normal operation.

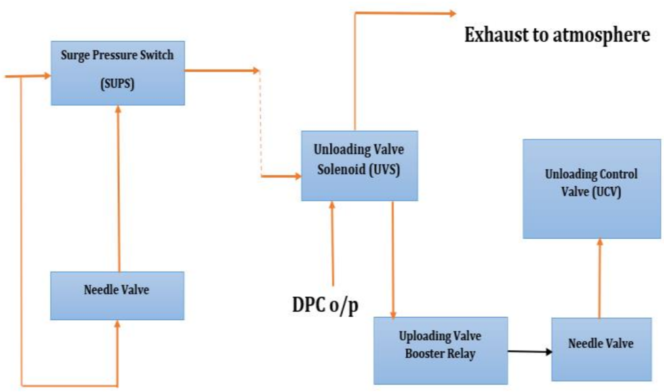

Fig-9: Surge protection system

If surge occurs, pressure at the low-pressure port of SUPS decreases rapidly, while pressure at the high-pressure port remains relatively constant by the restricting effect of NV2.The resulting pressure differential causes SUPS contacts to close, energizing control relay 2CR and lighting surge indicator on the annunciator. The normally open contacts of 2CR close to lock in the relay. The normally closed contacts open to de-energize UVS and exhaust the unloading valve actuator motive air signal to the atmosphere. The unloading valve opens, and compressor discharge pressure decreases, preventing further surging. Annunciator is extinguished and compressor returned to normal service by "Reset" button.

3.INTERLOCK

Today's chemical plants are operated close to their Safety limit. So, if some things go wrong with a process the system should quickly shut down to protect the personnel, plant, and process. And operator should get enough information to make an intelligent decision about the next move.

An interlock system consists of inputs (e.g., push buttons, limit switches, process switches and other external contacts) and outputs perform a defined function such as Start up or shut down through logical sequence of events as determined by certain hardware (such as relay contact arrangements in series, parallel or combination of both) and or programmed software.

3.1. PRINCIPLES OF INTERLOCK SYSTEM DESIGN

- Every system should tail to its lowest energy state or to a state from its critical operating limit.
- Interlock and safety system should be independent of all other plant process controls.
- Process control signals failure drive the final actuator to the fail safer direction
- All electrical components that make up an interlock circuit should be powered.
- Enunciators, alarms, indicating lights and electrical instruments expect these associated with interlocks should be powered independently from interlock system.
- Interlock circuit and their components should be designed to actuate the final operator in the direction required to cause the process to fail safe upon loss of power.
- Interlock and trip systems for each section of the plant and its related equipment should be designed so that failure of one system will not affect others.

3.2. CONTROL SYSTEM

Centrifugal compressor can be operated by two methods of control, modulate/Energy optimization Auto Dual (modulate+ two-step) depending on the requirement

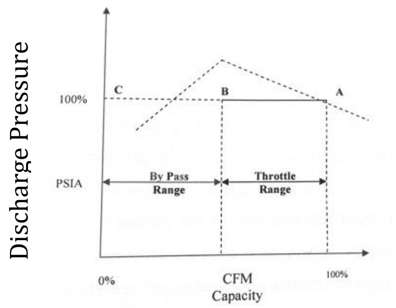

Fig-10: Centrifugal Compressor Control System

3.2.1. MODULATE CONTROL

This type of control maintains the system pressure at a constant value, which is accomplished by throttling the inlet valve withing the compressor range. If the system flow demand is less than minimum threshold capacity, constant discharge pressure is maintained by leaving the throttled capacity and throttling the bypass valve. Throttling the bypass valve provides capacity control from the minimum throttled capacity to zero capacity requirements. Modulate control panels contain unload and modulate control modes.

When the compressor is operated unloaded, the bypass valve is fully open, and the inlet valve is held partially open by a signal from the controller. The small amount of air that passes through the compressor, while in the unload mode, goes to the atmosphere through the bypass valve.

The compressor is at full capacity when the inlet valve is fully open, and the bypass valve is fully closed. At full capacity, the compressor is operating at point "A" on the performance curve. The controller will send the proper "full load signal to bypass and inlet valve when at point 'A' on the curve.

As flow demand decreases, constant discharge process is maintained by reducing the flow delivering to the system by throttling the inlet valve and keeping the bypass valve fully closed. The compressor will follow flow demand changes shown in the figure between 'A' and 'B' by throttling the inlet valve.

As flow delivery is reduced and the maximum inlet throttle range is reached, the compressor approaches its surge point. Any further reduction in compressor capacity would cause the unit to become unstable and operate within the surge region. To prevent the compressor from the operating within this region, the inlet valve is held open by the control signal at the maximum inlet throttle point.

As system flow requirements continue to decrease below the inlet throttle range of the compressor, the compressor will continue to follow their demand by blowing off surplus air through the bypass valve. The compressor will follow demands between point 'B' and 'C' by throttling the bypass valve.

Details of the Compressor
Here motor used is Outdoor mounted weather conditioned Squirrel Cage Induction Motor.

Table-2: Motor specifications

Specifications	
Full load rpm	2984
Service Factor	1.15
Volt/Phase/freq.	6600V/3/50 Hz
Motor full load current	96.8A
Locked Rotor Current	532 A
Heater Watts	660W
Heater Volts	230V
Heater Phases	1
Efficiency at 125% of nameplate HP	93.5
Efficiency at 100% of nameplate HP	92.5
Efficiency at 75% of nameplate HP	91.8
Efficiency at 50% of nameplate HP	89.5
Power factor at 125% of nameplate HP	0.903
Power factor at 100% of nameplate HP	0.911
Power factor at 75% of nameplate HP	0.908
Power factor at 50% of nameplate HP	0.883

Heater is placed within the motor enclosure to prevent the condensation of moisture. Space heaters internal connections are either series or parallel lines are brought to one of the space heater terminal boxes and connected during installation.

Table-3: Compressor Specifications

ELLIOT COMPRESSOR SPECIFICATION	
Model No.	610DA3
Driver Speed	3000 rpm
Rated Inlet Capacity	5770 CFM
Rated inlet air pressure	98kg/cm^2
Rated inlet air temperature	37 C (98.6F)
Rated discharge pressure	8.488kg/cm^2(120.7 psi)
Rated inlet water temperature	32C (89.6F)
Maximum inlet water pressure	125psi

4.LADDER DIAGRAM FOR AUTOMATIC COMPRESSOR CONTROL

Table-4: Component Name and its function

Component Name	Function
5LT-Indicator Light	It indicates permissive start-compressor ready for automatic start-up.
7LT-Indicator Light	It indicates auxiliary oil pump operation
9LT-Indicator Light	It indicates compressor drive is running.
1CR-Control Relay	Starts or Stops driver and locks in PB 1
2CR-Control Relay	De-energizes UVS when energized by SUPS or 2TR contacts
3CR-Control Relay	It de-energizes ICR when energized by HOTS
4CR-Control Relay	It de-energizes ICR when energized by HATS
PB1-Push Button	It starts compressor by energizing ICR
PB-2 Push Button	It stops compressor by de-energizing ICR
2TR-Timing Relay	It loads compressor automatically after start-up and driver has reached rated speed. Also locks out AOPS to prevent a low oil pressure alarm during start-up and shut up.

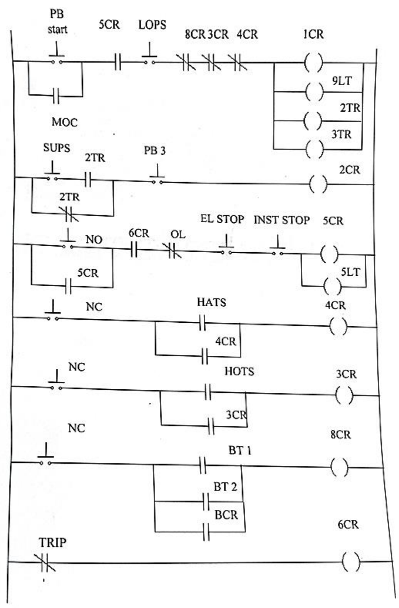

Fig-10: Ladder Diagram for Compressor Control.

5.CONCLUSION

In Plant Air Package systems (PAP), the air must be delivered at constant pressure. The compressor must be protected from unwanted operations such as surge, high temperature and pressure. So, it is better to use an automated control system using Programmable Logic Controller. By using PLC, we can provide permanent fault monitoring and control system which further increases the reliability and system performance. PLCs are much more reliable and are way easier to troubleshoot. The mechanical functions of relays simply wear out over time. Plus, the wiring required to operate a relay system is much more complicated than a PLC system. This can also cause higher costs to install and upgrade due to extra labor costs. One of the major advantages is the versatility of a PLC with its programming and internal relays, timers, counters, among other features.

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BIOGRAPHIES

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