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A SE Approach to Designing and Developing of Motion Control for Radioactive Waste Decontamination

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Abstract : Decontamination of systems, structures and components (SSC) during the decommissioning of a Nuclear Power Plant (NPP) can be for a variety of reasons. The main reasons for decontamination are: to reduce the contamination of SSC to a reasonably low level, to reduce the potential for the spread of contaminants into the environment and to reduce the cost of disposal due to the reduced level of contamination in a particular SSC. The decontamination technique can be aggressive or non-aggressive depending on the intent after the decontamination process. Aggressive decontamination technique is used when the intent is not to reuse the SSC while a non-aggressive decontamination technique is used with the intent of SSC reuse. For different SSCs there are different decontamination techniques that can be used, each having its own advantages and drawbacks. Metal components such as pipes in the nuclear power plant account for a large amount of nuclear wastes generated. Some of these wastes can be reused if the contaminant level is reduced to an acceptable level. Laser ablation is a non-aggressive decontamination technique that can be used to reduce the contamination in pipes to an acceptable level with no secondary waste generated during the process. The operation and control of a laser ablation device must be precise to achieve a high decontamination factor. This precision can be achieved by a well-designed motion control system. For this purpose, a motion control system was developed consisting of two parts: the first part being the precise control of the laser ablation device inside the pipe and the second part is the control of the laser ablation device outside the pipe. This paper describes the Systems Engineering approach for the development process of a motion control system for the Laser decontamination system.

Key Words : Decontamination, Laser Ablation, Motion Control, Systems Engineering, Requirements, Testing

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1. Introduction

In the nuclear power plant, wastes are produced during the operation life of the plant and after the operation life of the plant. A very significant amount of wastes that are produced are from metallic components, structures, and systems. These metallic components often time can still be reused but due to the contamination levels with these components, they are not. The removal of contamination from surfaces of facilities or equipment by washing, heating, chemical or electromechanical action, mechanical cleaning, or other techniques can be referred to as decontamination.[1] Decontamination can be done in two ways depending on the intention:

- During operation of the nuclear plant whereby the components still have to be maintained and not damaged for continuous operation of the plant.
- During decommissioning whereby the components status is dependent on the intent after decommissioning.

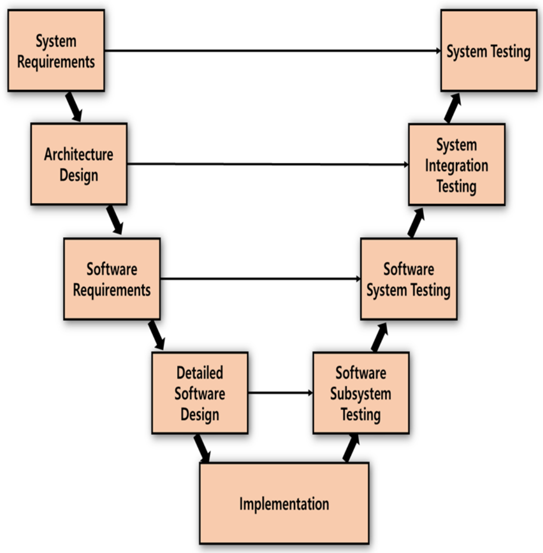
For metallic wastes such as pipes, the intent mostly is to reuse the components due to the fact they were manufactured with the highest of quality standards. For this reason, an efficient decontamination technique is required.

There are different types of decontamination techniques for different structures and components and they tend to have their advantages and disadvantages. Of these techniques, laser ablation is type of decontamination technique that removes material from a substrate by absorption of laser energy.[2] The resulting local shockwave is sufficient to eject the paint/coating from the surface of the metal.[3]

These laser ablation devices for decontamination purposes in the nuclear plant are still ongoing research areas.[3],[4]

And according to these research, an integral aspect that determines a high decontamination factor is the motion control of the laser ablation device.

The development of an efficient motion control system for the light ablation device was the focus of the research. Systems engineering approach was adopted for the development of the motion control subsystem which is a part of the radiation waste decontamination system being developed. In this paper, the life cycle process for the system is described.

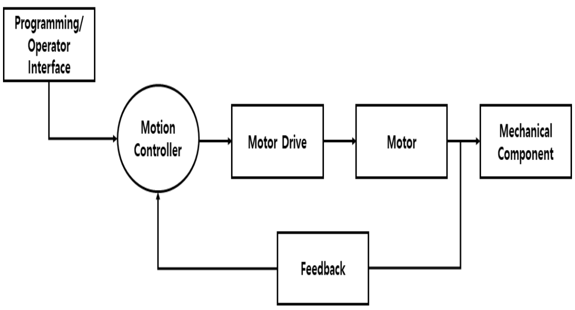


[Figure 1] Systems Engineering Process

Figure 1 shows the development process that will be discussed in this paper. This paper is organized as follows: Section 2 describes the theory and overview of motion control system. section 3 describes the systems engineering approach that was applied for the development of the motion control system. Section 4 describes the conclusion of the paper.

2. Methodology

The importance of motion control system to the laser ablation system cannot be over emphasized as the efficiency of the decontamination process is dependent on the precise control of the laser ablation device. Motion control can be simply defined as the precise and coordinated control of moving parts of a machinery. It can also be defined as the precise control of anything that moves. Motion control system is widely used in various fields in order to develop automated systems, such as precision engineering, micromanufacturing, nanotechnology and biotechnology.[5] Motion control systems mainly consists of five components: the mechanical device being moved, the motor with feedback and motion I/O, the motor drive unit, the motion controller (intelligent controller) and the programming/operator interface software.[6] Figure 2 shows the motion control system.



[Figure 2] Motion control block diagram

The programming/operator interface is a PC based automation system that was developed for the precise control of the laser ablation system. The motion controller is responsible for higher computation and decision making, while the servo drive is responsible for the delivery of signals from the controller to the servo motor. The servo drive serves as an amplifier that amplifies the signals from the motion controller. The servo motor is the component that converts the electrical signals into rotation movement.[7] Finally, the feedback sensors record the performance and sends information to the motion controller. There are a variety of operating modes in a motion control system, some of which are: point-to-point movement, jog mode, and homing mode.

In point-to-point movement, each axis is independently programmed with motion profile parameters such as velocity, acceleration, unit per pulse, velocity profile and the target position. This mode is used to move the servo motor precisely from point to point.

In the jog mode, the servo motor runs at a set velocity and continues to run until a stop signal or a different command is entered. This mode can be used to manually position the motor. The homing mode is used during system initialization and startup. In this mode, when the motor is started, it goes to the home position. The home position is obtained from the feedback signals from the limit sensors on the mechanical device being driven.

3. Systems Engineering Approach

Figure 1 shows the systems engineering process applied for the development of this paper. The process starts with the system requirements, then the software requirements down to the implementation and testing. Each of the phases will be discussed in the following sub sections.

3.1 System Requirements

System requirements are the foundation of the system definition and form the basis for the architecture, design, integration, and testing. The system requirements specify the system characteristics, attributes, functions, and performance.[8] The system requirements as elicited by the stakeholders are:

i. The motion control system shall provide adequate control of the motion control system by providing an input for unit per pulse which is the moving distance and provide adequate feedback through a realtime velocity profile chart and encoder position feedback.

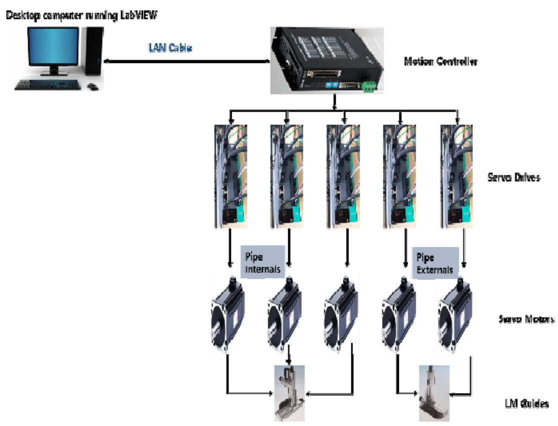
ii. The motion control system shall be able to precisely move the laser ablation device from point to point and vary the speed of the motion control system via user defined inputs.

iii. The motion control system shall have different modes of operation. These modes shall be standby mode, absolute mode, jog mode and homing mode.

iv. The motion control system shall have different stop modes. the stop modes are: decelerating stop mode and emergency stop mode.

3.2 Architecture Design

This is the top-level system design. The system architecture as shown in Figure 3 shows the desktop computer running the LabVIEW software, the motion controller controlling the servo drives and the servo motors. The servo motors are connected to a linear motion guide (LM Guide) which converts the rotational motion of the motor to a linear motion. The laser ablation device would be mounted on the LM guide.



[Figure 3] System architecture

The project is aimed at controlling 5 servo motors, three of the servo motors will control the laser ablation device inside the pipe while the remaining two will control the laser ablation device outside the pipe.

3.3 Software Requirements

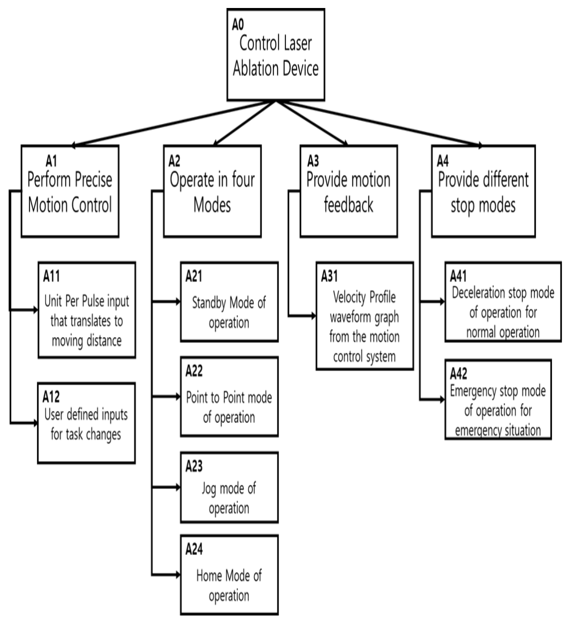
Software requirements include capabilities that a user needs to solve a problem or achieve an objective as well as capabilities that a system or component needs to satisfy a contract, standard, or other formally imposed document.[9] Software requirements can be categorized with the following: functional requirements, external interface requirements, and design constraints.[10]

3.3.1. Functional Requirements

The functional requirements of the motion control system are the specific functions that the system must perform in order to meet the system requirements.[10] These requirements are:

- The software shall be designed to precisely control the laser ablation device through a developed human machine interface. The unit per pulse mentioned in the system requirements also refer to the moving distance. The unit per pulse shall be dependent on the number of pulses for an instance of movement of the motion control system. For instance, the number of pulses required for a 10mm movement is 1000, Therefore, the unit per pulse that the user or operator inputs into the motion control system is 0.01. The knowledge of the type of servo motor is important for the unit per pulse configuration which translates into moving distance for the motion control system.
- The software shall be able to provide inputs for different conditions or modes of operation. In the event that the length of the pipe being decontaminated changes, the software shall have provisions for operators to make changes based on the tasks.
- The design shall have four modes of operation. Standby mode where the system is ON and not moving, Absolute mode where the motion control system can be precisely controlled to move from one point to another, JOG mode where the motion control system can be manually operated until a stop or change signal is sent and the last mode is the Home mode where the motion control system would be made to return to its home position when the signal is given.
- The design shall have two stop modes which are deceleration and emergency stop. The deceleration stop mode can be used when there is no emergency, such as when the motion control system is being controlled beyond the normal operating conditions and this could damage the laser ablation system and could cause damage for surrounding components and or systems. Emergency stop can be used in the event where deceleration can not be used.

Figure 4 shows the functional architecture as described above.



[Figure 4] Functional architecture for motion control system

3.3.2. External Interface Requirements

The motion control system having both hardware and software components should be able to send instructions from the software and receive feedback from the hardware. the interface requirements between these components therefore are:

- The system shall have a standard communication interface between the hardware and software.
- The communication interface shall be able to transmit at least 10Mb/s.

The interface in this case would be an ethernet cable of category 5 at the minimum. The motion control system requires both hardware and software to function as a system. The hardware and their descriptions are described as follows:

3.3.2.1. Motion controller

The motion controller acquired for the project was from P.A.I.X. The model is NMC2E−220 which provides 2−axis motion control. The motion controller is powered by 24V DC power supply.

NMC2E-220

Specifications

제품특징	2축 제어 서보&스텝모터 펄스제어 LIMIT+, LIMIT−, ORG (NEAR) Trigger 출력 UART통신 (RS232, RS485) MPG입력 PTP, 직선 · 원호보간, 동기운전, 겐트리구동, 상대 · 절대운전 S−curve가감속 비대칭 사다리꼴 가감속운전, 삼각파 방지기능
옵션품	모션 케이블 LAN케이블 NMC2E−UART COM보드 Trigger컨버터
제품크기	사용 온도 : 0~55℃ 사용 습도 : 5~90% (응결없음) 보관 온도 : −20~70℃ 무게 : 300g 크기 : 136.5mm(H) x 39mm(W) x 106mm(D)

[Figure 5] Motion controller specifications

Figure 5 shows the motion controller and its specifications.

3.3.2.2. Servo Drive

The servo drive acquired for the project was from LS Mecapion and the model was L7PA008U. The specifications of the servo drive are shown in Figure 6.

Part	Description
Input Power	AC 220[V]~230[V]
Capacity	100[W]~3.5[kW]
Rated Current	1.4[A]~16.7[A]
Encoder	Incremental, Biss-B,Biss-C(Absolute, Incremental)
Communication Type	RS-422(ANSI/TIA/EIA-422) / USB2.0(HID)
Control Mode	Velocity, Position, Torque
Feature	Pulse-in/Index mode

[Figure 6] Servo drive specifications

3.2.2.2. Servo Motor

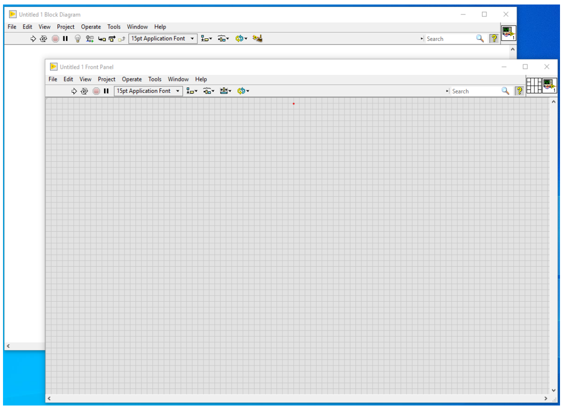
The servo motor acquired for this is LS AC servo motor and the model was APMC−FCL08AMK. The Specifications of the servo motor are shown in Figure 7

Part	Description
Rated/Max rpm	3000/5000 (rpm)
Rated/Max torque	2.39/7.16 (N.m)
Rated/Max current	5.02/ 15.07 (A)

[Figure 7] Servo motor specifications

3.2.2.3. Design Constraints

The hardware is managed by a software called LabVIEW. Laboratory Virtual Instrument Engineering Workbench (LabVIEW) is a system−design platform and development environment for visual programming language from National Instruments which can be used for data acquisition, instrument control, and industrial automation.[11] The software was used for the development of the motion control system. The design and development panels for LabVIEW on Windows is displayed in Figure 8.

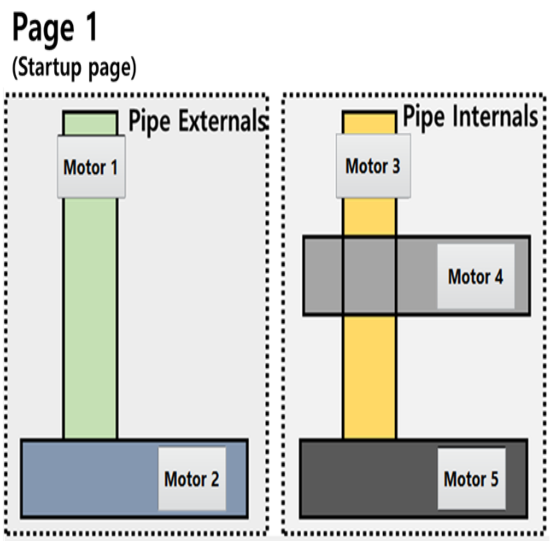


[Figure 8] LabVIEW front panel and block diagram

The communication interface between the computer running the software program and the motion controller is the ethernet hub.

3.4 Detailed Software Design and Implementation

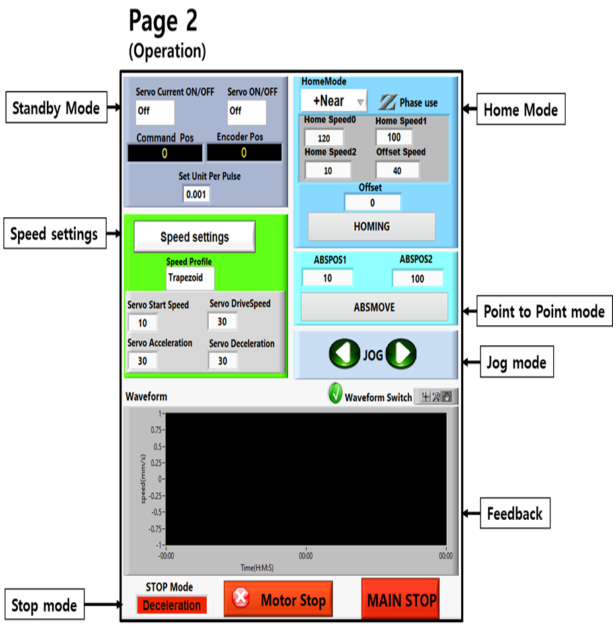
The detailed software design and implementation covered the development of the codes and designing of the user interface for the control of the laser ablation device though the servo motors. The design as stated in the requirements of this project had the different modes of operation, the interactive user interface and an emergency stop or deceleration button. The coding was done in the LabVIEW block diagram while the user interface was designed in the LabVIEW front panel. The block diagram made use of different structures such as case structures, event structures, and while loops. These structures and other library functions were used for the development of the codes.



[Figure 9] Startup page of the motion controller user interface

Figure 9 and Figure 10 show the startup page of the motion control user interface and the selected servo motor control interface respectively. As seen the figures, the requirements were satisfied by the implemented design. In Figure 10, it can be seen that the requirements have been satisfied in the design. it contains the standby mode, homing mode, point to point mode, jog mode, stop modes, feedback, speed settings and unit per pulse user control input. Though this design satisfies the requirements, it is still in its development phase and is still subject to more improvements.

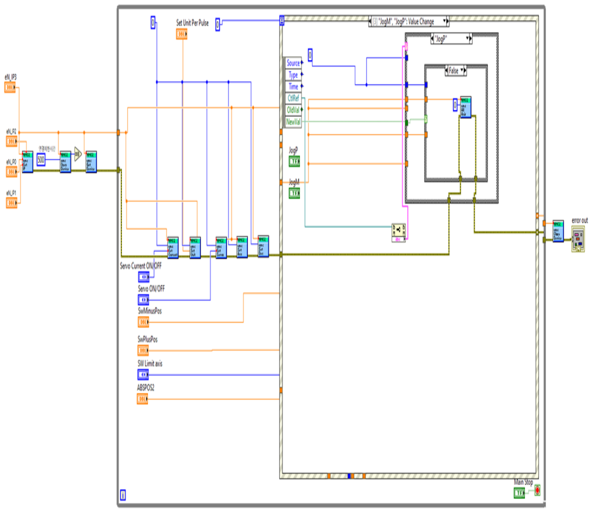
Figure 9 shows the startup page interface for the motion control system. As shown above, the externals of the pipe has two motors and the internals have three motors. The motors would be controlled one at a time. Outside the plant, the motion axis are two, X and Y axis. One motor moves in the X−axis and the other moves in the Y−axis on the outside of the pipe. The motors on the inside of the pipe are three and they move in the XYZ−axis respectively.



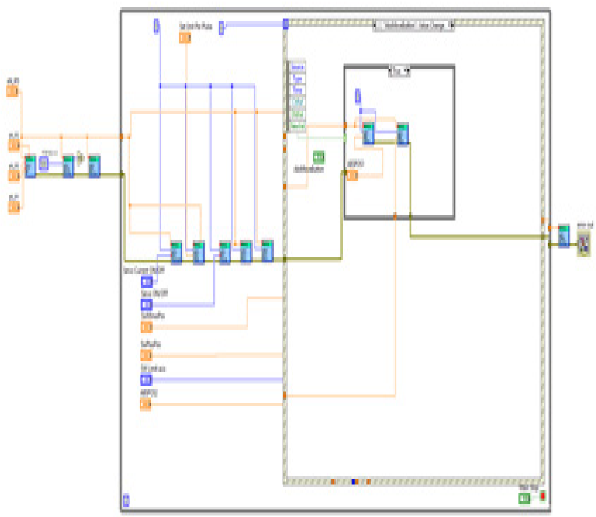
[Figure 10] Control interface for servo motor 1

The control interface as stated in this paper was developed using LabVIEW. Figure 10 shows the front panel for the motion control system. This act as the interactive panel for the control of the system being developed. This font panel is as a result of some control logic developed on the block diagram of the LabVIEW. An illustration of the block diagram for one of the modes of operation is shown in Figure 11.

As shown in Figure 11, the logic has acombination of while loops, event structures and case structures. The CASE STRUCTURES executes one of the two cases if the condition is met. The cases involved for the jog mode are positive jog and negative jog. The EVENT STRUCTURES creates the initiating condition for the case structure and the WHILE loop ensures that the process runs continuously. The global WHILE loop runs the Jog Mode cases and the Standby modes.



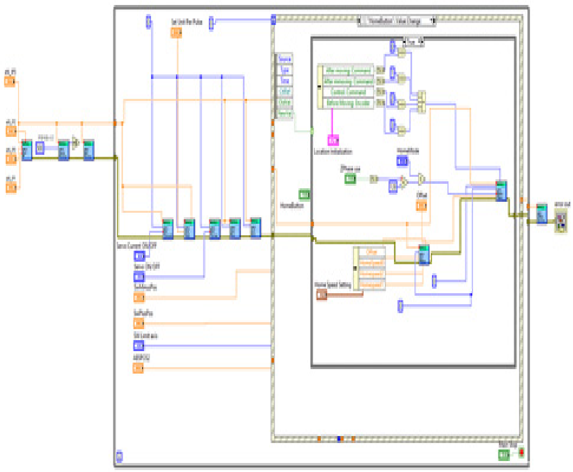
[Figure 11] Control logic for Jog mode



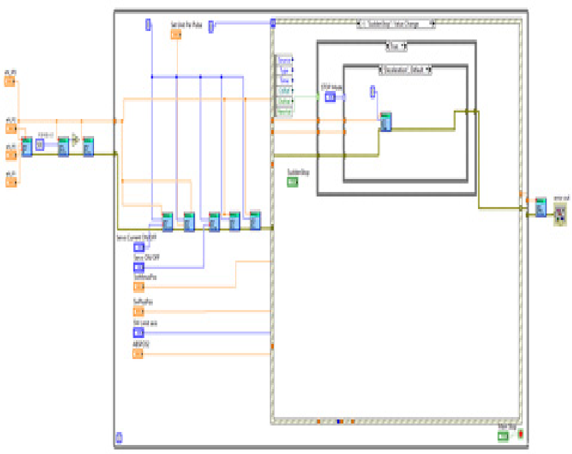
[Figure 12] Control logic for Point to Point mode

Figure 12 shows the control logic for the point to point movement of the motion control system. The same combination of structures apply tho this logic.

Figure 13 and Figure 14 show the control logic for the Home mode and the Stop modes for the motion control system.



[Figure 13] Control logic for Home mode



[Figure 14] Control logic for the two stop modes

3.5 Testing

The software subsystem testing, software integration testing, software system testing, system integration testing and system testing were all performed by demonstration. The software subsystem testing for each module was integrated with the hardware and a demonstration was carried out. In other to fully test the software subsystems and integrated system, the design had to interact with the hardware which in turn covers the system integration testing. The tests show that the design had no errors. at the end of the testing phase, all the requirements defined in the system requirements were satisfied.

4. Conclusion

The application of laser technology for decontamination is an area that is being developed and there is a need for high decontamination efficiency. This efficiency is dependent on different factors and one of the factors is the type of control being employed for the laser ablation device. This paper showed how systems engineering was applied for the development of a motion control system for the laser ablation device. This design is meant to be deployed in the field and to be used for the control of the laser ablation device in the decontamination of nuclear waste (pipes). This design through tests has shown to perform the tasks as required, is still under development and after some feedback from the stakeholders, some design upgrades would be made to make the user interface less complicated.

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