Consideration of a two-phase excitation control method for stepping motors used in HANARO's control rods

Jiye Jeong*, Changdong Lee, Minwoo Lee, Yuntaek Im, Youngsan Choi, Minsu Kim, Seunggyu Doo
HANARO Management Division, Korea Atomic Energy Research Institute
898-111 Daeduk-Daero., Yuseong-Gu, Daejeon, Republic of Korea
**Corresponding author: jiye8713@kaeri.re.kr*

HANARO (High-flux Advanced Neutron Application Reactor) is a research reactor located in South Korea. The HANARO contains four control rods that are used to regulate the rate of the reaction during normal operation and adjust the output of the reactor. This article provides a detailed overview of the control rod system of the HANARO, which is composed of various components, including stepping motors and motor drivers. The motors in the control rods are operated using a 1-phase excitation control system, which can sometimes result in slipping of the control rods. To address this potential issue, the paper considers the possibility of implementing a 2-phase excitation control system and discusses the differences between the two systems. Overall, this paper presents valuable insights into the HANARO control rod system and its potential for future developments.

1. Introduction of HANARO

HANARO, which stands for "High-flux Advanced Neutron Application Reactor," is a research reactor located in Daejeon, South Korea. HANARO is used for a variety of purposes, including basic and applied research in material science, biotechnology, and environmental science, as well as production of radioactive isotopes for medical and industrial applications [1]. The HANARO is a high-performance research reactor, generating a thermal output of 30MW, and ranking among the top 10 most powerful research reactors in the world. Noticeably, the reactor uses low-enriched uranium with an enrichment level of 20%, which distinguishes it from conventional nuclear reactors that often use highly enriched uranium as fuel.

Despite generating approximately 1/100th of the output of a typical commercial nuclear power plant, HANARO is considered safer than larger reactors due to its design and operating conditions. The reactor is submerged in a water tank filled with 318 tons of water, which provides both cooling and radiation shielding. Even in the event of a power failure, the heat generated by the reactor can be safely dissipated by natural convection of the water. The open water tank design also allows for the supply of additional cooling water in case of an emergency. The reactor has several safety features in place to prevent the release of radioactive material in the event of an accident.

Furthermore, HANARO undergoes regular inspections by the International Atomic Energy Agency (IAEA), has a comprehensive quality assurance program, and employs highly trained staff. All these factors make HANARO a safe facility for scientific research and industrial applications.

1.1. Control Absorber Rods Drive System of HANARO

The HANARO is equipped with four Control Absorber Rods (CARs) and four Shut Off Rods (SORs) as in Figure 1 [3]. The CARs regulate its power output while SORs enable a direct shutdown of the reactor. The primary function of the SORs is to rapidly and safely shut down the reactor in emergency or planned situations by inserting cylindrical hafnium tubes into the core.

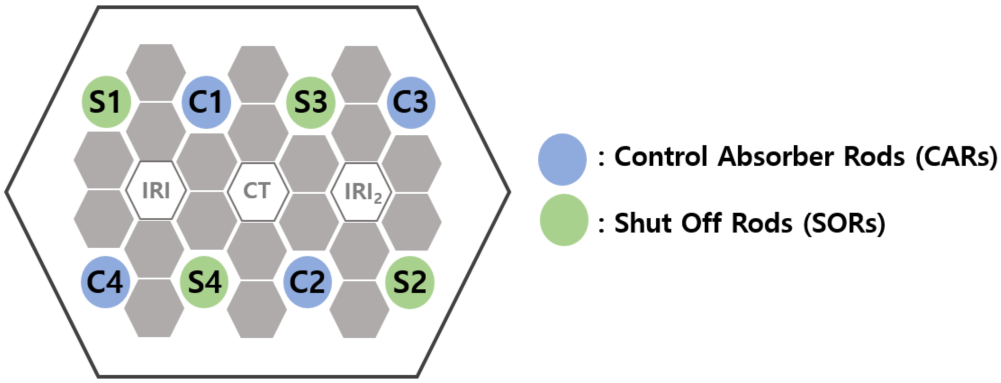

Figure 1 : Location of CARs and SORs in the core [3]

The control absorber rods drive system is responsible regulating the neutron and heat output of the reactor to maintain safe and efficient operation. Only one Control Rod can move up or down at a time, and if two or more control rods are unavailable, the reactor must be shut down [3].

The Control Absorber Rods Drive System consists of three parts: Absorber Element Assembly, Control Absorber Rods Drive Assembly and Rod Control System (RCS).

The Absorber Element Assembly is used to control the reactivity of the core in a nuclear reactor by inserting, withdrawing, or maintaining neutron-absorbing material at any position within the reactor core. The assembly consists of several components, including hafnium tubes, shrouds, tracks, and carriages.

The Control Absorber Rods Drive Assembly is a mechanical unit that moves the control rods up or down upon receiving a drive signal. This assembly is located inside the chimney and is connected by an upper tie rod to the RCS. There are several components of the assembly such as motor, a lead screw, a drive nut, a tube, and a dry well, as depicted in Figure 2. The CAR is moved up or down within the reactor core by a stepping motor turning a lead screw. The rotational motion of the stepping motor is converted into linear motion through a drive nut attached via a connecting tube to an electromagnet, dry well, and upper tie rod. The Absorber Element Assembly moves up or down accordingly.

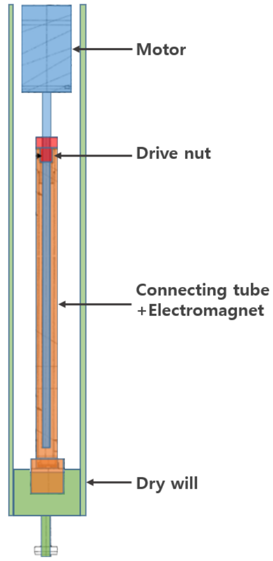

Figure 2 : Simplified Configuration of CAR Drive Assembly [3]

The RCS is an Instrumentation and Control (I&C) system responsible for generating and delivering the driving signal to the Control Absorber Rods Drive Assembly. This system can be divided into four parts: controller, counter card, motor driver and encoder. The Figure 3 describes the driving signal flow of CARs from Controller to stepping motor.

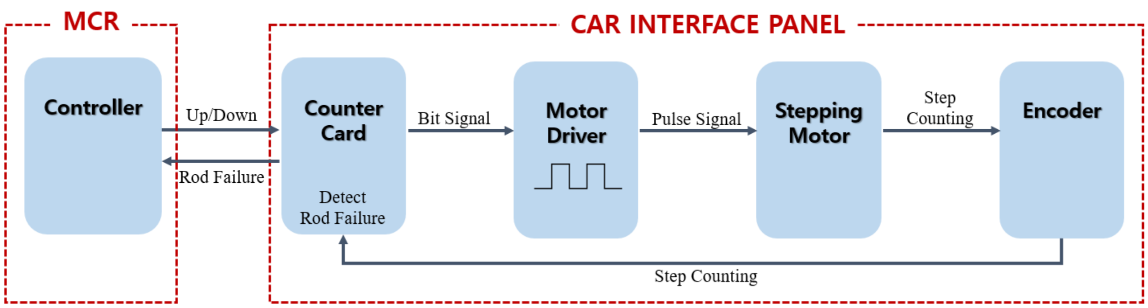

Figure 3 : Driving Signal Flow

The controller installed in Main Control Room (MCR) generates the driving signals for moving the control rods up or down and reports failures in the movement of the control rods. The counter card in the CAR interface panel has two functions. Firstly, it converts the driving signal containing the number of steps and direction of rods received from the controller into a bit signal. Secondly, it detects failures, such as step errors, time-out errors, driver errors, and power supply errors, to the Controller.

The role of motor driver is to convert the bit signals received from the counter card into pulse signals. Specifically, the motor driver transforms each bit signal into 16 pulse signals, with each pulse that is used to drive the motor.

The encoder is responsible for monitoring the motor's actual running phase and transmitting this information to the counter card. This information is then sent to the controller, which compares it with the commanded value. If there is a difference greater than 3 steps, an error is generated by the controller. This mechanism ensures that the system operates within a tight tolerance, promoting safe and reliable operation.

2. Analysis of control methods based on excitation methods

2.1. Analysis of the current excitation method used in the HANARO

The stepping motor is an electromechanical device that is commonly used in nuclear power plants and research reactors to control the position of control rods. In HANARO, the stepping motor utilizes a one-phase excitation control method and features a rotor with 50 N-poles and 50 S-poles. The one-phase excitation control method requires four steps per cycle, with each step causing a 1.8-degree movement. This means that the rotor must complete 200 steps to complete one full rotation. Figure 4 illustrates the sequencer of one-phase excitation motor.

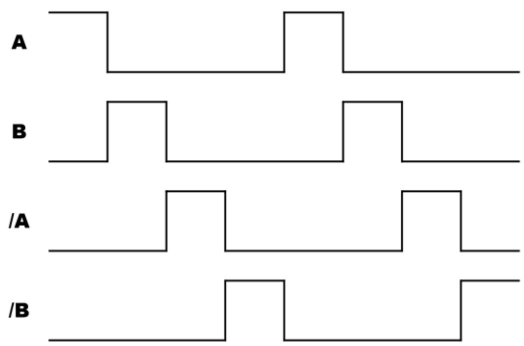

Figure 4 : Sequencer of One-phase Excitation Motor

The choice of one-phase excitation control system in HANARO is based on two primary considerations. Firstly, it offers lower power consumption compared to two-phase systems, which is particularly important in applications where power efficiency is a priority. Secondly, one-phase excitation control systems are generally simpler, making them easier to maintain and develop. These factors make one-phase excitation control an attractive option for controlling the position of control rods in nuclear reactors.

However, there are also several disadvantages to consider. One major issue is the out-of-control phenomenon of the motor, which can cause control rods to slip out of place. In one case, a malfunction occurred due to poor internal wiring in the motor, resulting in the pulse signal required to drive the stepping motor not being transmitted properly. This caused a gap between the intended operating position and the actual position of the control rods, which lead to generate an abnormal alarm and shut down the reactor. In addition, one-phase excitation control systems can also lead to increased vibration and noise levels. This is because the rapid fluctuations in current can cause the rotor to vibrate and generate audible noise, which can be problematic in certain environments. Therefore, it is important to carefully evaluate the potential disadvantages of the one-phase excitation control system before making any changes to the control system.

2.2. Investigating the feasibility of implementing the two-phase excitation method

To address the challenges mentioned in section 2.1, HANARO is currently considering a two-phase control method. Compared to one-phase systems, two-phase excitation control systems can provide smoother and more precise motor movements. This is because they generate more phases of current, enabling more accurate control of the motor. In addition, it is possible to prevent the control rods from slipping out. There are two options to adjust the two-phase excitation control system. The first option is to upgrade the motor drive using a current stepping motor (4-lead motor), while the second option is to upgrade the motor drive using an 8-lead stepping motor. This paper discusses the considerations for implementing the two design improvement methods.

The first case is upgrading the motor drive with a current stepping motor to implement the two-phase control system by using CPLD (Complex Programmable Logic Device) which is a general-purpose device applied in the fields of measurement equipment and automobiles, requiring precise timing. To enhance the motor drives, it is necessary to consider the excitation sequencers and current controllers. Figure 5 shows the sequencer of two-phase control system and Figure 6 shows the configuration of motor driver device. The motor driver is composed of an excitation sequencer, a current regulator, and a power module. The excitation sequencer generates the logic for motor excitation from the microprocessor, while the current regulator generates a signal to control the current [4].

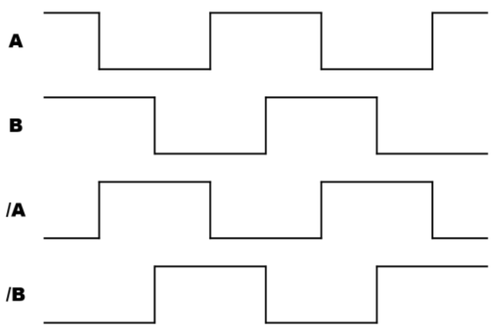

Figure 5 : Sequencer of two-phase

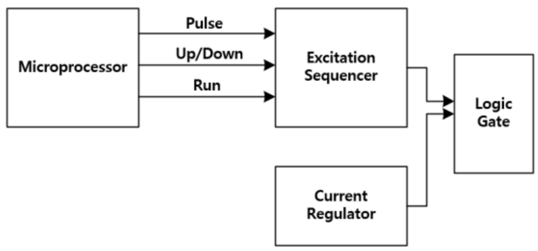

Figure 6 : Configuration of driver device

In general, there can be a problem of current ripple and vibration caused by the noise effect of the current flowing through the stepping motor. When this is based on the current excited in one-phase, the sum of the current excited in the two-phase is multiplied by $\sqrt{2}$. Therefore, in order to maintain a constant torque, the two-phase current must be controlled differently. This means that it is necessary to adjust the reference current according to the two-phase excitation in order to achieve more precise control [5]. Maintaining a constant torque of the stepping motor and reducing irregular vibration are crucial for achieving high performance in two-phase excitation control systems [4]. Various methods can be used for this purpose, including the addition of a diode or the use of a digital filter to remove harmonic components. The choice of method depends on the specific control device being used. Therefore, selecting the appropriate noise reduction method for the device is essential in achieving the desired motor performance.

The second option involves upgrading to an 8-lead stepping motor. Figure 7 illustrates the differences between the two types of motors [6].

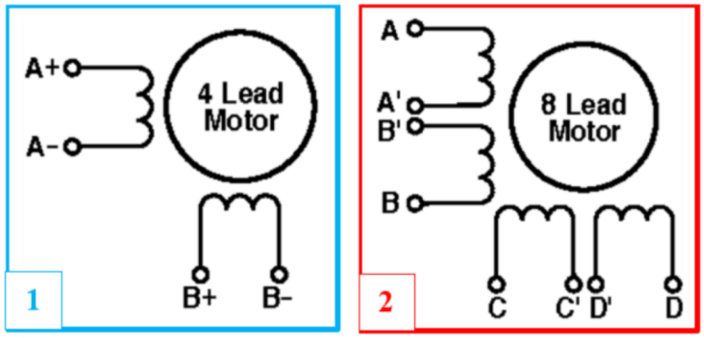

Figure 7 : Differences between 4-lead Motor and 8-lead Motor [6]

As shown in Figure 5 and Figure 7, there is a possibility of malfunction if either the A phase or B phase is disconnected. Although the 2-phase design of Figure 5 has a lower possibility of malfunction than the current design, it is still a concern. Therefore, adjusting the connection of each phase with a redundancy design is necessary, which is the concept behind the 8-lead motor design. This 8-lead design allows the motor to operate at higher speeds and achieve its rated torque, but it may also result in higher current consumption. Therefore, when designing the motor drive, the power supply to the motor should also be carefully considered.

3. Conclusions

In this paper, we have analyzed the Control Absorber Rods Drive System of HANARO and identified areas for improvement. Specifically, we have found that the current 1-phase control system can lead to the slip of control rods, resulting in a discrepancy between the operator's intended position and the actual position. This discrepancy can ultimately lead to the shutdown of the research reactor.

To address this problem, we have proposed a solution in the form of a 2-phase control system. This can be achieved either by upgrading the design of the motor drive or by designing a new motor with a new driver. We have proposed an upgrade to the motor drive with a CPLD to address the slip issue in the Control Absorber Rods Drive System. During the upgrade, it is essential to consider the current ripple and noise. These issues can be addressed through the addition of a diode or digital filter, but the optimal solution may vary depending on the model of the motor driver. Therefore, when upgrading the motor drive, it is crucial to consider its compatibility with the motor and the addition of suitable design to ensure optimal performance. While the proposed method significantly reduces the probability of slips, it cannot completely prevent them. Therefore, to eliminate slips entirely, it is necessary to consider a design change to an 8-lead motor with a new motor driver. The 8-lead motor offers a redundant connection cable, ensuring high reliability in the system's operation.

In conclusion, this study has provided important insights into the improvement of the Control Absorber Rods Drive System of HANARO. However, to fully implement the proposed upgrades and ensure optimal performance, further detailed design studies are needed. It is essential to continue research and development in this area to guarantee the efficient operation of nuclear reactors. The results of this study can serve as a foundation for future research and development efforts.

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