# CONCEPTUAL DESIGN OF CONTROL ROD DRIVE MOTOR TYPE MAGNETIC JACK FOR NUCLEAR POWER PLANT

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## ABSTRAK

**DESAIN KONSEPTUAL MOTOR PENGGERAK BATANG KENDALI PLTN TIPE MAGNETIC *JACK*.** Motor penggerak batang kendali (CRDM) berfungsi untuk mengendalikan daya reaktor dan memadamkan reaktor jika terjadi keadaan darurat. CRDM di Reaktor Serba Guna G.A. Siwabessy menggunakan motor tiga-fase yang menggerakkan *spindle* mur-bola melalui gigi transmisi. *Spindle* ini memutar masuk mur bola yang terpasang di dalam SCRAM magnet. Desain ini memiliki beberapa kelemahan, salah satunya apabila terjadi gangguan pada *limit switch* motor, maka mur-bola akan secara terus menerus berputar dan mengakibatkan ulir yang ada pada poros batang kendali menjadi aus karena gesekan dan terlepas dari pemegangnya. Pada kegiatan ini, dilakukan pengembangan terhadap motor penggerak batang kendali dengan tipe magnetic *jack* yang bergerak linier vertikal terhadap komponen poros ekstensi dan komponen batang kendali sebagai respons terhadap sinyal sistem digital penggerak batang kendali terhadap kontrol reaktivitas. Motor penggerak batang kendali ini harus mampu menarik, memasukkan, menahan atau menjatuhkan batang kendali dari titik mana pun. Desain konseptual motor penggerak batang kendali ini merupakan langkah awal dalam menentukan kriteria desain pembuatan prototipe sehingga diharapkan dapat mempermudah dalam memahami prinsip kerja motor penggerak batang kendali menggunakan *magnetic jack*. Simulasi gerakan pencengkeraman batang kendali juga disajikan menggunakan ANSYS *Rigid dynamics* untuk mengurangi terjadinya kegagalan pada tahap desain sebelum dilakukan pembuatan prototipe. Dari hasil simulasi diperoleh tidak ada benturan pada setiap komponen motor batang kendali yang dapat mempengaruhi performa sistem secara keseluruhan. Motor penggerak batang kendali dapat melakukan fungsinya untuk melakukan setiap langkah gerakan penarikan dan penurunan batang kendali pada jarak 19,1 mm dengan baik.

Kata kunci: batang kendali, magnetic jack, motor penggerak

## *ABSTRACT*

***CONCEPTUAL DESIGN OF CONTROL ROD DRIVE MOTOR TYPE MAGNETIC JACK FOR NUCLEAR POWER PLANT.*** *The Control Rod Drive Motor (CRDM) controls the reactor power of a G.A Siwabessy and automatically shuts it down during an emergency using a three-phase motor that drives a ball-nut spindle attached to the magnetic SCRAM through the transmission gear. However, there are several weaknesses associated with this design, such as the inability of the ball nut to rotate when a disturbance occurs at the motor limit switch continuously. This causes the threads on the control rod shaft to wear out due to friction and release from the holder. Therefore, this research aims to develop a CRDM with a magnetic jack for a nuclear plant, which moves the extension shaft and the control rod components vertically and linearly. The control rod's motor must pull, insert, hold, or drop it from any point. This conceptual design is the first step in determining prototyping design criteria with a magnetic jack to understand the working mechanism. The control rod gripping motion simulation was also presented using ANSYS Rigid Dynamics to reduce the failure at the design phase before prototyping. The simulation results showed no collision on each component capable of affecting the overall system performance. Therefore, the control rod motor functions properly in carrying out the pulling and lowering movements on 19.1 mm infrequency.*

Keywords: control rod, Drive motor, magnetic jack

## INTRODUCTION

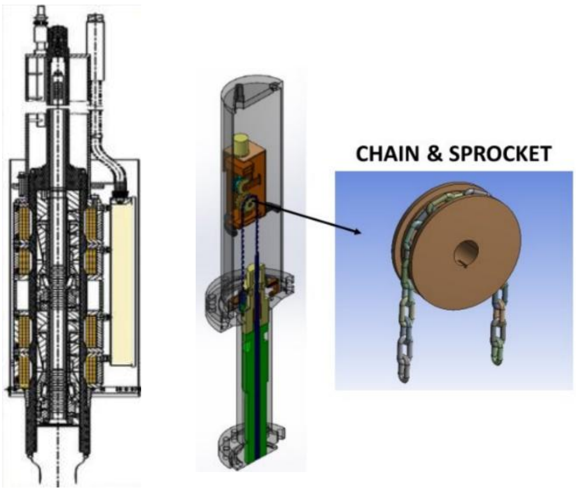
Since the technical revolution in the industrial revolution era in the 18th century, design is no longer visualized as art rather an engineering science studied and developed to solve technical problems [1]. It is inseparable from the investment factor for problem-solving by prioritizing technical functions. Therefore, the use of standardized materials to protect consumers and ease of assembly is mandatory, especially at the design stage of nuclear reactor components where safety and security are prioritized.

Computer technology plays an essential role in the simulation and modeling of systems during the industrial revolution. The simulation uses numerical evaluation of various mathematical models to describe the phenomena of a system. It is also used to describe various characters of complex systems for analysis [2].

Generally, power and non-power nuclear reactors are operated by controlling the neutron population in the reactor. The rod is driven with a linear movement mechanism against the extension shaft component of the digital system to determine its reactivity. Furthermore, it needs to be capable of pulling, inserting, holding, or dropping the control rod from any point and automatically shut down the reactor during an emergency [3].

Several types of control rod driving motors with varying mechanisms exist in power reactors. These mechanisms are dependent on the different operating environmental conditions for each type of reactor. Based on the operating environment, reactors are classified into non-pressurized and pressurized. In non-pressurized reactors, the control rod drive motor is placed openly to facilitate the monitoring and maintenance process. Meanwhile, pressurized reactors need to be reliable and durable due to the high temperatures and pressures in the operating environment.

The CRDM design for the Experimental Power Reactor (RDE) uses a chain to carry out the insertion and withdrawal of the control rod [4]. It is also used to determine the magnetic jack type, which is relatively cheaper to maintain [5]. It also uses a lever (jack) that moves horizontally by activating a magnetic coil in the motor housing. Figure 1 shows the construction of the magnetic jack and chain types of the control rod drive motor.




a. Magnetic jack type [6]     b. Chain type [4]

Figure 1. Comparison of magnetic jack and chain type CRDM construction

The type of CRDM in the PRSG-BATAN uses a three-phase motor that drives the ball-nut spindle through a transmission gear directly connected to the motor. This spindle rotates in the ball nut attached to the SCRAM magnet. During normal operations, the SCRAM retains the internal lifting gear with the connected control rod. However, it is unable to rotate the square housing due to its shape, while the control rod is raised or lowered by the lifting gear on the rotation of the ball-nut spindle. There are several weaknesses associated with this design, such as the inability of the ball nut to rotate due to a disturbance in the motor limit switch, leading to wear out due to friction continuously.

In this research, the conceptual design of the magnetic jack type nuclear power plant control rod motor with a different driving mechanism is used to determine the G.A Siwabessy and the experimental power reactors. A systematic approach is used to determine the technical function of the control rod drive motor design requirements. Simulation using ANSYS Rigid Dynamics is presented to reduce errors in the development process and ensure the design works properly.

## METHOD

The planning and development of the conceptual design of the control rod driving motor refer to the identification of the function and analysis variables of the failure mode in the system, as shown in Table 1.

This research aims to translate the profile of step and flow movements obtained from various research data previously carried out by Adebana et al. [6] into a conceptual design form, as shown in Figure 2.

Table 1. Variables of failure mode analysis on control rod drive motor [7]

| **Failure Mode** | ***Causing factor*** | ***Detection Method*** |
|---|---|---|
| Control rod motor coil malfunction | • ZCD card<br>• Coil drive card<br>• Phase sync. Card<br>• ACTM<br>• Filter panel<br>• Power supply | • Trends and current levels<br>• Transfer gripper<br>• Waveform comparison |
| Failure to hold control rod | • Power supply switch<br>• ZCD card<br>• Bad ground<br>• Power supply<br>• Phase sync. Card | • Current level<br>• Waveform<br>• Transfer gripper<br>• Control rod drop contact<br>• Surge |
| Electrical motion failure | • Current sensor<br>• SCR misfiring<br>• ACTM<br>• Lost phase<br>• Opto-isolation card<br>• Coil drive card<br>• Phase sync. card<br>• Power supply | • Position deviation<br>• Cycle time change<br>• Re-step<br>• Waveform comparison |
| Mechanical motion failure | • Increased friction due to latch and magnet moving slowly | • Time of surge<br>• Deviation against the time of the surge<br>• Cycle time change<br>• Waveform comparison |
| | • Damage to moving parts<br>• Position error | • Surge too early<br>• Slow sequential motion<br>• Cycle time change<br>• Waveform comparison<br>• Position deviation<br>• Control rod drop contact |
| | • Control rod drive motor coil degradation | • The current level in the control rod drive motor coil<br>• Waveform comparison<br>• Residual periodic variation of the DC voltage in the power supply |
| SCRAM failure | • Latch stuck<br>• Latch magnet stuck<br>• Control rod and extension shaft stuck | • No surge and shrinkage in current<br>• Cycle time change<br>• Re-step<br>• Waveform comparison |

## ANSYS RIGID DYNAMICS

The dynamics of rigid bodies against mechanisms that move at high speeds need to be analyzed due to the influence of mass distribution and shaft flexibility. This effect affects the dynamic response of the component movement, thereby leading to the inability to carry out its function [8].

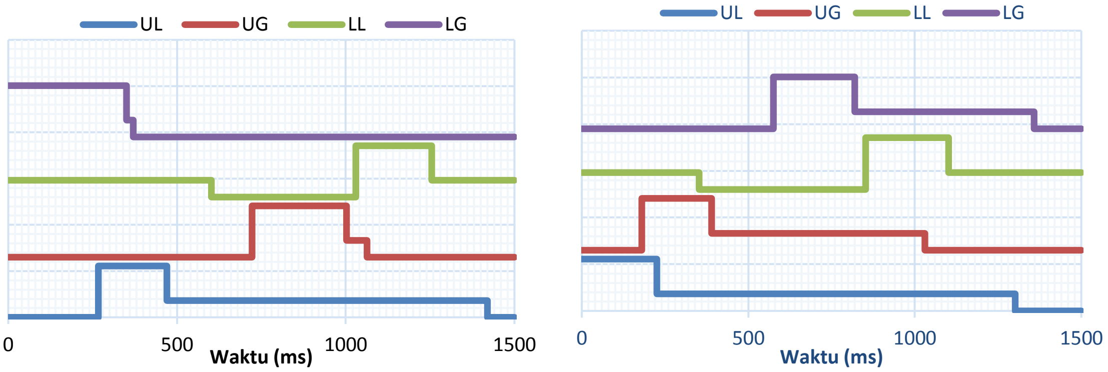
ANSYS is used to analyze rigid body dynamics to determine the movement of the control rod motor components to ensure there are no failures in the motor drive components due to collisions and friction.

## RESULTS AND DISCUSSION

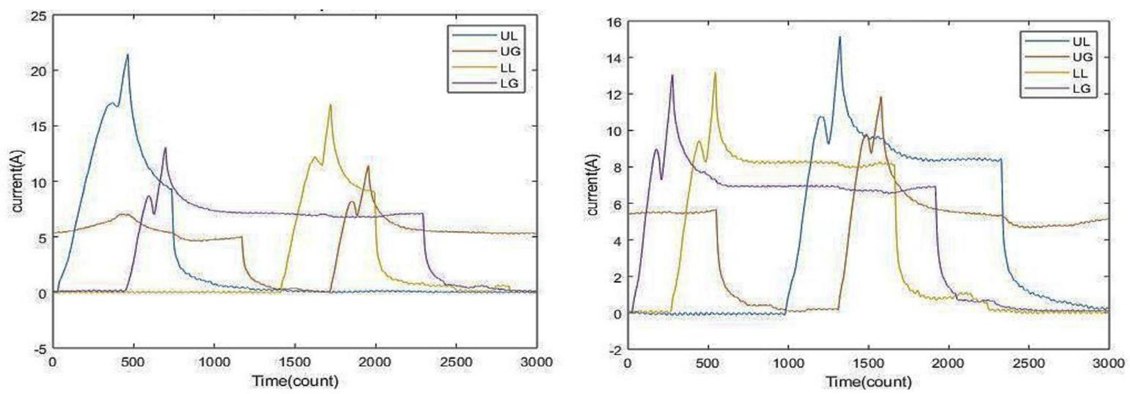
The function criteria in the control rod drive motor design requirements are shown in Figure 3.

The function is then translated into the components shown in Figure 4. The next stage is the conceptual design of the control rod drive motor, as shown in Figure 5.

Table 2 describes the insertion movement of the control rod. The movement of the withdrawal and insertion is carried out through the programmed electric current regulation in the magnetic coil. The setting conditions use a high, low, and negating current to perform the initial gripping motion, keep the latch in the gripping position, and carry out the opening motion of the latch.




(a) Movement steps (b) Insertion step




(c) Magnetic coil current for withdrawal movementd. Magnetic coil current insertion movement
Figure 2. Step and waveform profiles for control rod withdrawal and insertion movements [6]

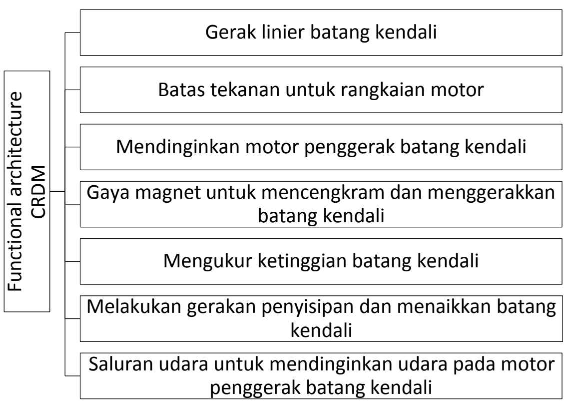



Figure 3. Functional architecture of control rod drive motor

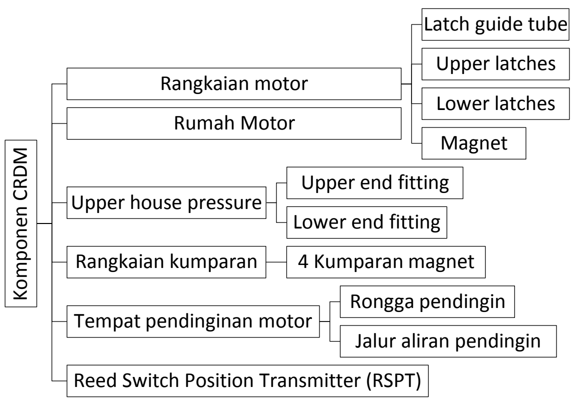
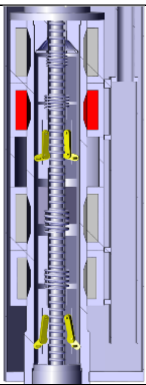
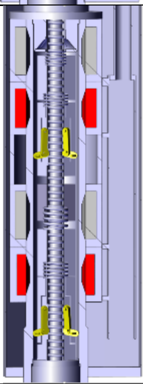
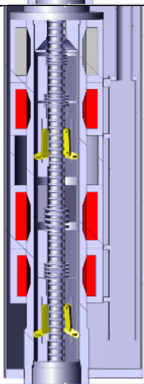
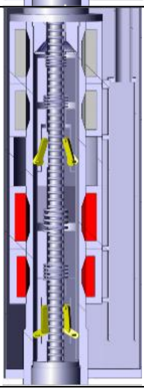
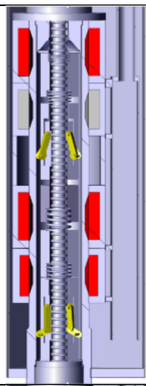
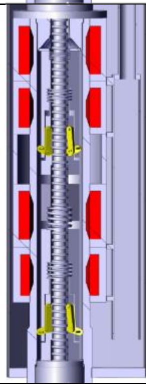
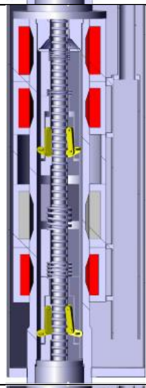
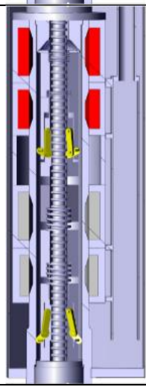
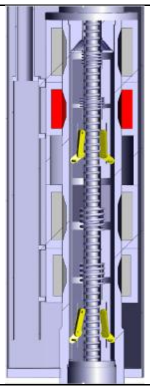



Figure 4. Physical architecture of control rod drive motor

Table 2. Simulation of control rod insertion movement

| No. | Motor movement | Description |
|---|---|---|
| 1 |   | The initial stage is gripping the control rod. This process energizes the upper latch coil, which starts to actuate the control rod gripping mechanism at the top. |
| 2 |   | The electrified lower latch coil starts to grip the control rod at a distance of 8.7 mm (11/32 in) from the bottom notches. |
| 3 |   | The lower lift coil is energized, causing the lower latches to move 9.5 mm (3/8 in) and lifting the control rod at 0.8 mm (1/32 in). In this step, the load from the control rod is fully resisted by the lower latch. |
| 4 |   | The electric current in the upper latch coil is removed, while the lower latch coil is electrified to keep the lower latch coil gripped by the control rod. |
| 5 |   | The upper lift coil is energized to drive the upper latch circuit up to 11.1 mm (7/16 in). |
| 6 |   | The upper latch coil is electrified and moves 11/32 inches. |
| 7 |   | The current in the lower lift coil is dissipated, causing the lower latch to drop 9.5 mm (3/8 in). The control rod moves down 8.7 mm (11/32 in), stops at the upper latch circuit, and then starts electrifying before moving to the up position. |
| 8 |   | Electric current in the lower latch coil starts being eliminated while electrifying the upper latch and lift coils. |

| | | |
|---|---|---|
| 9 |  | The upper lift coil's electric current starts dissipating, moving the upper latch circuit and control rod 11.1 mm (7/16 in). |

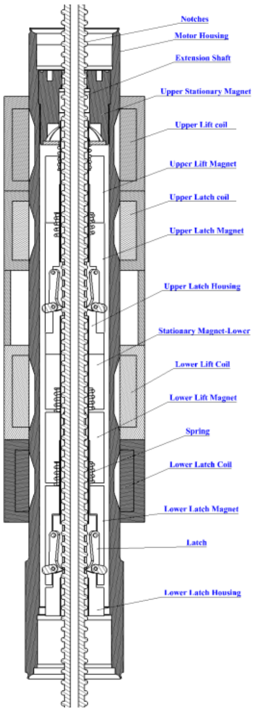



Figure 5. Control rod drive motor design

ANSYS Rigid Dynamics performs simulation tests and ensures that no collisions and friction damage the components. The simulation results are shown in Figure 6, with each movement of the withdrawal and insertion steps within a distance of 19.1 mm.

Normal operation of the reactor also includes full insertion of control rod groups during transient loads. Power is released from the coil during the SCRAM event, which automatically releases the latch from the CRDM drive shaft, allowing the control rod to fall by gravity. The CRDM operates independently of each other when the reactor trips and vice versa. In the event of a CRDM failure, the shutdown capability is maintained through the margin value in the reactor. Therefore, no single failure has the ability to prevent CRDM from providing sufficient reactivity to stop reactor operation.

The detailed steps of the insertion process described in Table 2 were obtained from the simulation using ANSYS Rigid Dynamics.

The sequential steps of the control rod withdrawal movement are shown in Table 2.

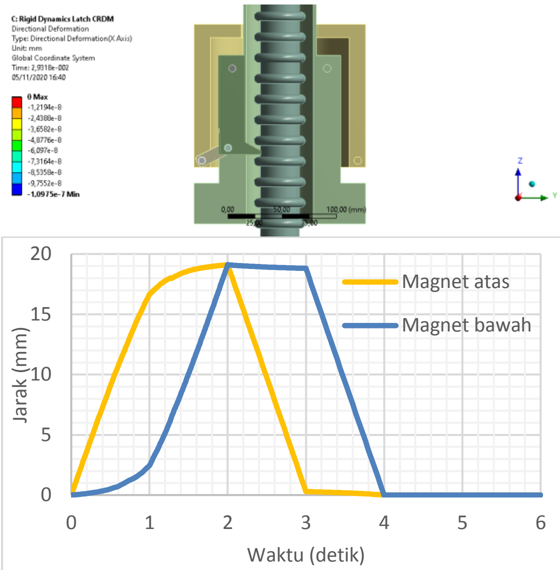



Figure 6. Simulation of control rod motor magnet movement

## CONCLUSION

The simulation results showed that the components experiencing problems had no movement, affecting overall system performance. Therefore, the withdrawal and insertion movement of the control rods enabled each step within 19.1 mm to work properly.

Further studies need to be carried out at the design stage, especially regarding the strength of the structural integrity of the component materials, the power required to drive the motor, and the system's reliability.

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