MECHATRONIC DESIGN AND ANALYSIS OF REAKTOR DAYA EXPERIMENTAL COMPONENTS

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ABSTRACT
A mechatronic design and analysis of Component for RDE has been conducted. The mechanical design and electrical power system analysis are important auxiliary system arranged for the component of RDE component test loop to each its safety and operation objective. In order to achieve the above goals the system based on mechanical and electrical power flow are analyzed. In this paper consists of mechanical and electrical system drawings, as well requirement of design and analysis that will be presented as the outcome of the design component part of RCCS-RDE Test Loop. The mechanical analysis is simulated by CATIA, and electrical power system analysis is simulated by ETAP.

Key words: mechatronic, power system analysis, RCCS and RDE.


1. INTRODUCTION
Experimental Power Reactor Development (Reaktor Daya Ekeperimental / RDE) will be enabled by Indonesia to gain experience and the ability to realize and operate the first power plant that can produce electricity as well as heat steam for industrial needs. The proposed
RDE is a high-temperature gas-cooled reactor, which is capable of generating electricity and can meet other applications (cogeneration), such as coal liquefaction and gasification, increased oil enrichment, smelter requirements and seawater desalination, as well as hydrogen production [1].

At present, BATAN has made its own Pebble Bed Reactor (PBR) type experimental reactor (RDE) design with little energy to master this technology. The plan has so far been realized in the preparation of the conceptual design in 2015, the drafting of the basic design in 2017 and detailed preliminary design preparations planned for 2018. High temperature gas nuclear reactors, especially the pebble bed (PBR) type reactors are one of designs for advanced generation reactors which are very safe. This type of reactor offers excellent safety features and potential cogeneration applications. For Indonesia, PBR is one of the attractive candidates that can provide solutions for national energy needs in the form of electricity and at the same time heat for the needs of modern industrial development. The study of the design of High Temperature Gas Reactors (RGTT) and their application in Indonesia including the development of software for HBW design has been carried out by BATAN since the 90's. Since the last two years, BATAN has taken the initiative to carry out PBR design studies by designing 10 MW RDE.[2,3,4].

To support the success of the RDE program and once to validate the RDE design, a number of RDE sub-system testing facilities have been established such as : Fuel Handling System (FHS), Helium Purification System (HPS) and Reactor Cavity Cooling System (RCCS). The three test facilities require a stable power supply system and a good design in terms of power system analysis using the ETAP software. In addition, all three systems must be equipped with reliable grounding systems and lightning rods to protect critical equipment. [5,6,7].

![RDE System Block Diagram](image)

**Figure 1** Block Diagram of RDE System [8]

### 2. DESCRIPTION OF RCCS

The design of RCCS Reaktor Daya Eksperimental (RDE) as shown in Figure 2
The RCCS test loop is used to simulate passive heat transfer decay, and the core power density as well as the annular core configuration have been designed. The decay heat can be removed by conduction to the pressure vessel and removed by radiation from the vessel to the cavity cooling system reactor without exceeding the particle particle temperature limit burn. The mechanical and electrical system in adjusted actual condition for test loop must have sufficient supply of electrical energy especially for power supply heater and a reliable protection system. The test facility shall be equipped with a neutral ground earthing system, since neutral ground earthing systems will affect the measurement results in the instrumentation system. [9,10,11]
Figure 3 shows that the main TR-1 transformer supplying the test facility is designed to be sufficient for the electrical energy requirements of the test facility. In addition, the protection system equipment must function properly in the sense that the protection system must have good coordination, which means that if the Circuit Breaker on CCTL trip then the only option to switch off CB in QMF-8 instead of CB in PC 1. The rating and the settings of CB as well as fuse protection equipment are important. The electrical load flow analysis using ETAP is important for determining the flow of load and the setting of safety component protection on RDE electrical supply CCTL.

**Power System Calculation using Etap**

Simple modeling of the electric bus system on the three RDE test loop is shown in Figure 4.

![Bus model of electric power system RCCS](image)

Figure 4 Bus model of electric power system RCCS

\[
\frac{P_i - jQ_i}{V_i^*} = V_i \sum_{j=0}^{n} y_{ij} - \sum_{j=1}^{n} y_{ij} V_j \quad j \neq i \quad [1]
\]

Load flow analysis has been conducted by selecting the rating of electrical system components consisting of generators and transformers. Loads must be represented or modeled through an single line diagram by assuming a balance three phase system. This diagram is intended to provide a brief overview of the overall electrical system, in this case the power system of the power supply to the three test facilities in the RDE.[12]

The input data associated with these components are the data system of electrical power supply in RDE component test loop the building number 80 PTKRN BATAN, such as: Data generator (genset data), ie active power capacity (P) in units Megawatt (MW) and reactive (Q) in units Megavolt Ampere Reactive (MVAR), terminal voltage (V) in kilo Volt (kV) and synchronous reactance (X) in Ohm (Ω) units. Power Transformer Data, ie capacity of each transformer in Megavolt Ampere (MVA), voltage (V) in kilo Volt (kV) and leakage reactance (X) in Ohm (Ω) units. The data of transmission line, ie resistance (R) in ohm (Ω) and reactance (X) in Ohm (Ω). The load data, ie the active power (P) in Megawatt (MW) and reactive power (Q) in Megavolt Ampere Reactive (MVAR) units.[13]

### 3. SCOPE AND METHODOLOGY

The step of analysis for mechanical system uses CATIA and the electrical power system analysis for RCCS based on the load flow of calculation uses ETAP. Flow chart of mechanical analysis and electrical power system analysis is shown in Figure 6.
Power flow calculation steps with the \textit{Newton-Raphson} method are as follows:[13]

1. On different bus where \( P_{\text{sch}}^i \) and \( Q_{\text{sch}}^i \) the value is determined. The magnitude of the voltage and phase angle is equal to the reference bus value of 1.0 and 0.0, so \( V_{i(0)} = 1.0 \) and \( \delta_{i(0)} = 0.0 \). For the generating bus where \( VI \) and is set, while the phase angle is equal to the reference bus angle, then \( \delta = 0 \).
2. Calculate \( P_i^{(k)} \) and \( Q_i^{(k)} \) on the load bus, and calculated \( \Delta P_i^{(k)} \) and \( \Delta Q_i^{(k)} \)
3. Calculate \( P_i^{(k)} \) and \( \Delta P_i^{(k)} \) on the generating bus.
4. Compute the Jacobian matrix elements \( J_1, J_2, J_3 \) and \( J_4 \)
5. Calculate the value and \( \Delta V_i^{(k)} \) and \( \Delta \left| V_i^{(k)} \right| \)
6. Calculate the new values of phase and voltage angles, \( \delta_i^{(k+1)} \) and \( \left| V_i^{(k+1)} \right| \)
7. This process continues until the value is \( \left| V_i^{(k+1)} - V_i^{(k)} \right| \leq \epsilon \)

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure5.png}
\caption{Flow Chart of Mechatronic System Design of RCCS}
\end{figure}

4. RESULTS AND DISCUSSIONS
4.1. Mechanical Design and Analysis
The RCCS-RDE design is planned to be operated at a maximum pressure of 2 bar and a maximum temperature of 90 °C to fulfill the safety design requirements. Mechanical strength analyzes include von misess stress (mechanical stress) and translational displacement in one of the rccs-rde components. The RCCS-RDE component analyzed is manifold, and the election is
based on the material used in the manifold component which is pyrex glass and considered as the weakest material of mechanical strength, while the other component uses stainless steel 304 material. The mechanical properties of pyrex material 7740 are used as material manifold components and used them as input data for mechanical strength analysis simulation as follows: Yield strength is $6.9 \times 10^7$ N/m², Density is 2230 kg/m³, Young’s modulus is $6.4 \times 10^9$ N/m², Thermal expansion is $32.5 \times 10^{-7}$/°C and poisson ratio is 0.2. Von mises stress analysis results on RCCS-RDE manifold are shown in Figure 7.

![Figure 6 Von Mises Stress Analysis Results on RCCS-RDE Manifold](image)

From the figure 6, the results showed the greatest stress occurred in the flange of $1.31 \times 10^7$ n / m² while the yield strength of pyrex material 7740 was $6.9 \times 10^7$ n / m². If the results of the analysis of the greatest stress compared with pyrex 7740 yield strength material, the greatest stress is still much smaller than the yield strength of 7740 pyrex material and still in the material elastic region. So if the load of pressure and temperature are eliminated then the manifold will return to its original shape. Analysis of the translational displacement of the RCCS-RDE manifold is shown in Figure 8. This test aims to determine the occurrence of form changes in the RCCS-RDE manifold.

![Figure 7 Analysis of the Translational displacement of the RCCS-RDE Manifold](image)

From figure of 7, If the test results in translational displacement are very large compared to the size of Manifold, then there has been a change of shape on the Manifold. The largest translational displacement analysis of the RCCS-RDE Manifold is 0.603 mm. The translational displacement is so small that it does not alter the shape of the Manifold and does not suppress or interfere with other components. It can thus be concluded that the Manifold...
bermaterial pyrex 7740 can be used as one of the RCCS-RDE components planned to be operated at a pressure of 2 bar and a temperature of 90 °C.

4.2. Electrical Design and Analysis

Electrical system design of RCCS power supply consists of electrical single line diagram and electrical load flow analysis. The single line diagram electrical power supply of RCCS RDE test loop facility is shown in Figure 8.

Figure 8: Electrical Single Line Diagram of RCCS Power Supply using ETAP

Figure 8 shows a single line diagram with field data input on PC1 panel and PLN transformer TR-1, also data obtained from the load design for load requirements of test facilities to be installed.

The load flow analysis of RDE Test Loop Facility using ETAP is shown in Figure 8. It shows that the voltage 0.38kV comes from Genset 600 kW of power and electrical supply from PLN ,TR-1. The loads connected to the system Panel PC-1 0.38kV are : RCCS Panel, Fuel Handling System Panel and Helium Purification System Panel.

Figure 9 shows the load flow analysis of the three test facilities showing both the active and reactive power flow, as well as the average power factor on each panel and the voltage drop on the load component. The value of active power, reactive power, current and average power factor can be shown in Table 1. The voltage drop values in the test facility load components are shown in Table 2.
Figure 9 Electrical Load Flow Analysis of RCCS Power Supply using ETAP

Table 1 Active and reactive power flow

<table>
<thead>
<tr>
<th>From bus</th>
<th>To Bus</th>
<th>Load Flow</th>
<th>Current (Amp)</th>
<th>PF (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>P (kW)</td>
<td>Q (kVAR)</td>
<td></td>
</tr>
<tr>
<td>Genset</td>
<td>Panel PC-1</td>
<td>104</td>
<td>36</td>
<td>166.7</td>
</tr>
<tr>
<td></td>
<td>Control System</td>
<td>2</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Fuel Handling</td>
<td>Compressor-1</td>
<td>27</td>
<td>14</td>
<td>46.2</td>
</tr>
<tr>
<td></td>
<td>Compressor-2</td>
<td>27</td>
<td>14</td>
<td>46.2</td>
</tr>
<tr>
<td></td>
<td>Control System</td>
<td>2</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>HPS</td>
<td>Coil Heater</td>
<td>3</td>
<td>0</td>
<td>5.3</td>
</tr>
<tr>
<td></td>
<td>Tubler Heater</td>
<td>6</td>
<td>1</td>
<td>9.1</td>
</tr>
<tr>
<td></td>
<td>Control System</td>
<td>2</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>RCCS</td>
<td>Rectangular Heater</td>
<td>34</td>
<td>7</td>
<td>53.2</td>
</tr>
</tbody>
</table>

From table 1 shows that the load flow of active power P from 2 kW to 34 kW and the reactive power from 1 kVAR to 14 kVAR. The total power of active is 104 kW and 36 kVAR of reactive power. The power factor of load is 0.89 to 0.99.
Table 2 Normal voltage and voltage drop in normal condition

<table>
<thead>
<tr>
<th>Bus Name</th>
<th>Bus Voltage (kV)</th>
<th>Calculation results (ETAP)</th>
<th>Voltage (kV)</th>
<th>Voltage. (%)</th>
<th>Drop in $V_{mag}$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC-1 Panel</td>
<td>0.380</td>
<td>0.380</td>
<td></td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>Fuel Handling</td>
<td>0.380</td>
<td>0.3789</td>
<td>99.70</td>
<td></td>
<td>0.3</td>
</tr>
<tr>
<td>HPS</td>
<td>0.380</td>
<td>0.3797</td>
<td>99.93</td>
<td></td>
<td>0.07</td>
</tr>
<tr>
<td>RCCS</td>
<td>0.380</td>
<td>0.3791</td>
<td>99.76</td>
<td></td>
<td>0.24</td>
</tr>
<tr>
<td>TR-1</td>
<td>20/0.380</td>
<td>0.380</td>
<td>100</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Cable-1</td>
<td>0.380</td>
<td>0.378</td>
<td>99.7</td>
<td></td>
<td>0.30</td>
</tr>
<tr>
<td>Cable-4</td>
<td>0.380</td>
<td>0.379</td>
<td>99.93</td>
<td></td>
<td>0.07</td>
</tr>
<tr>
<td>Cable-6</td>
<td>0.380</td>
<td>0.379</td>
<td>99.76</td>
<td></td>
<td>0.24</td>
</tr>
</tbody>
</table>

From table 2, the voltage drop that occurs on the PC-1 panel bus is zero % (0 kV) from the normal voltage of 0.380 kV. Voltage drop at the Fuel Handling System panel is 0.30 % (22.1 Volt), voltage drop in HPS panel is 0.07% (3 Volt). The voltage drop at RCCS from the normal voltage of 0.380 kV to 0.379 kV or 0.24 % (9 Volt).

5. CONCLUSIONS

The results of mechanical strength analysis include Von Mises Stress (mechanical stress) and translational displacement in pyrex material which is the weakest material yield safe conclusion to use from safety side when operated. For other component material Stainless Steel 304 is also safe to use because the material has mechanical strength which is greater than pyrex material 7740.

Electrical power system analysis on RDE component test loop has been conducted using ETAP software. The designed of power system analysis and also to overcome the problem of under voltage are simulated by Etap. The load flow analysis is the analysis of active power flow (P) and reactive power (Q) from the generating system through the transmissions and distribution system to the load. The total of power that flows depends on the amount of load mounted on the bus. The active power flowing from main panel bus (PC-1 bus panel) is 104 kW and 36 kVAR of reactive power. The voltage drop at component is from 0 % to 0.3 %. The power factor is 0.89 to 0.99 above the requirements of Government Electricity Company PLN, so that the power flow is in good condition.

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