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MODELAREA SISTEMULUI DE RĂCIRE A ETANŞĂRILOR POMPELOR PRINCIPALE DIN CIRCUITUL PRIMAR DE TRANSPORT AL CĂLDURII LA CNE CERNAVODĂ

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CNE CERNAVODA NUCLEAR POWER PLANT PRIMARY HEAT TRANSPORT PUMPS GLAND SEAL COOLING SYSTEM MODEL

Primary Heat Transport Pumps Gland Seal Cooling System scope is to provide a high pressure D_2O cooling flow to the primary heat transport pumps seals. The system safety function is to maintain Primary Heat Transport System pressure boundary integrity and to prevent radioactivity releases. In order to monitor the seal operation and to warn of a possible malfunction or failure, the papers propose an operation model, based on an electric-hydraulics similarity.

Keywords: pumps, gland seal, mathematical model, electric-hydraulics similarity
Cuvinte cheie: pompe, presgarnitură, model matematic, similitudine electric hidraulică

1. Introduction

CANDU (CANada Deuterium Uranium) nuclear reactors uses natural uranium as fuel and heavy water (D_2O) as neutron moderator and cooling agent. Heavy water (D_2O) is a highly efficient moderator because of its low neutron absorption capability, so natural uranium fuel can be use.

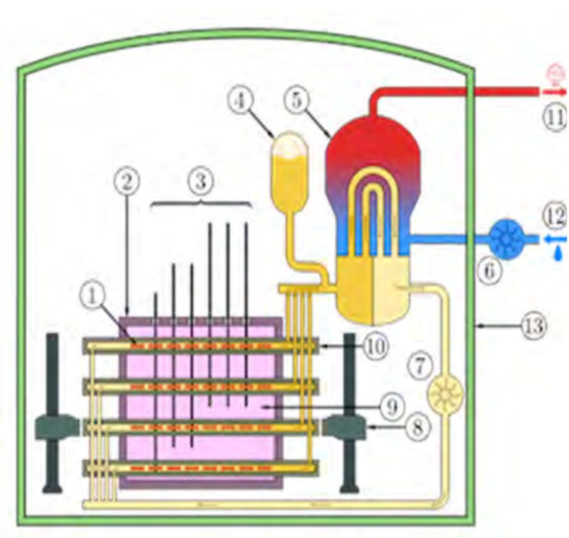

Fig. 1 Schematic of a CANDU reactor

1 – fuel bundle of natural uranium, 2 – reactor vessel (calendrical), 3 – reactivity control rods, 4 – pressurizer, 5 – steam generator, 6 – light water pumps, 7 – primary heat transport system pumps, 8 - fueling machine, 9 – heavy water moderator, 10 - fuel channels, 11 – steam to turbine, 12 – light water supply to steam generator, 13 – reactor building (containment) (Credit imagine: Creative Commons)

The main heat transport system pumps circulate pressurized, high temperature, heavy water through the main heat transport system. The pumps are vertical, centrifugal, single stage, with single suction and double discharge [2].

Each main heat transport pump has its own gland seal assembly which consists of a replaceable seal "cartridge", in which is located a system of shaft seals (three mechanical seals and a back-up seal). The shaft seals scope is to prevent D_2O leakage from the main heat transport system [3].

For their normal operation, the mechanical seals require a supply of cool and clean high pressure heavy water.

The system safety function is to maintain primary heat transport system pressure boundary integrity and to prevent radioactivity releases [2].

2. General presentation

2.1 The primary heat transport pumps cooling system

Primary heat transport system pumps gland seal cooling system consist from a pipeline arrangement where the heavy water flow is provided from D_2O feed pumps discharge is filtered, and distributed to seals of the four main heat transport system pumps. This represents the injection flow which is required for gland seal cooling system normal operation [3].

The injection D_2O flow mixes with the flow recirculated by the pump, flows through the external heat exchanger and enters into the pump in the front of the lower seal and above the auxiliary impeller. A small amount of flow is maintained through the seals and provides lubrication and cooling. The rest of the flow is recirculated by the auxiliary impeller and a part of this flow passes through the thermal bushing into the volute case. This flow prevents high temperature D_2O from entering into the seal cavity. After passing the seals a part of the flow is found as leakage through the third seal and goes to the heat transport D_2O collection system, and another part (return flow) is discharged into the heat transport system D_2O Storage Tank via the gland return lines [2].

2.2 Primary heat transport pumps seal system

The primary heat transport pumps glands are retained between the pump casing and the bottom flange of the motor stand.

Each gland, houses a system of shaft seals, which consists of an auxiliary impeller, three identical high pressure mechanical seals and a back-up seal [4].

Each of the mechanical seals is in parallel with a seal throttle. The seal throttles all have the same hydraulic resistance and control the flow through the seal. An assembly of a mechanical seal and a seal throttle is considered a seal stage [4].

The mechanical seal consists from two parts, a fixed carbon made ring, located in an enclosure, and a moving tungsten carbide made ring, mounted in a sleeve. The moving part is pressed to the fixed part by resorts, obstructing the D_2O flow along the shaft. Pressure drops on each of the three seal stage are relatively equal. For a properly functioning seal, the flow through the rotor/stator interface should be minimal [4].

After passing the mechanical seal, the D_2O flow is directed to D_2O Storage Tank, after which it is returned in the circuit [3].

When the final pressure exceeds the normal value, it is observed an abnormal flow outward on a parallel branch to the normal, moving toward D_2O collection tank [2].

From hydrodynamic point of view, the space between the two parts represents a hydraulic loss.

3. Process modeling

3.1 Modelling goal

The goal of the study is to elaborate a mathematical model of the D_2O flow through the sealing system. The main applications of the model are:

- Establishing flow that cross the seals and the flow that enter into the pump, total flow being knows.
- Verifying the D_2O flow losses, using theoretical means, considering the risks of the direct measurements and the necessity of losses prediction.
- Simulating different abnormal situation, using theoretical means, and without any risks for the equipment, environment and human health.

3.2 Hypotheses

The mathematical model is based on an electrical-hydrodynamic similarity, considering each mechanical seal and seal throttle as electrical resistance, the pressure at the inlet and the outlet of the stage as electrical potential, and the last seal as a capacity, which is pierced when the pressure after the third seal exceed a certain value.
The electrical model is presented in figure 2.

For further calculation, the flow passing through seals is considered negligible, and only the flow passing through the seal throttle is taken into consideration.

For having simulation results as close as possible to reality, the actual measured values of seals cavity pressure as are displayed on CNE Cernavodă Unit 1 Main Control Room monitors are taken into consideration.

After the auxiliary impeller the first cavity pressure is 95 bars, after the first stage the second cavity pressure is 65 bars, after the second stage the third cavity pressure is 33 bars, and after the third stage, the D_2O flow goes Storage Tank and the pressure is considered 1 bar. So the total pressure drop across all three seal stages is 94 bars.

The main data used by the model are:

- total pressure drop across all three stage is $\Delta p = 94 \cdot 10^5\ N/m^2$;
- length of the pressure balance line is $l = 3.3\ m$;
- inlet diameter of the pressure balance line is $d = 0.0035\ m$;

- total flow enter into the seals is $Q_{total} = 0.25 \cdot 10^{-3} m^3/s$;
- flow circulating effectively through seals is Q';
- flow enter into the pump is Q'';

$$Q_{total} = Q' + Q'' \tag{1}$$

- roughly kinematic fluid viscosity coefficient taken into consideration is $\nu = 10^{-4}\ m^2/s$;
- gravity coefficient is $g = 9.81\ m/s^2$;
- water density is $\rho = 1000\ kg/m^3$.

3.3 Hydraulic computation

According to the scheme, the hydraulic resistance is calculated based on Darcy's relationship is

$$h = \lambda \frac{l}{d} \frac{v^2}{2\,g} \tag{2}$$

The fluid flow is considered laminar, so linear coefficient of miscarriage is

$$\lambda = \frac{64}{Re} \tag{3}$$

$$Re = \frac{d\,v}{\nu} \tag{4}$$

For flow through the annular channel

$$v = \frac{4\,Q\prime}{\pi\,d^2} \tag{5}$$

$$Re = \frac{4\,Q'}{\pi\,d\,\nu} \tag{6}$$

$$\lambda = \frac{64\,\pi\,d\,\nu}{4\,Q\prime} \tag{7}$$

$$h = 128 \frac{\nu\,l}{\pi\,d^4 g}\ Q' \tag{8}$$

According to the scheme and considering that the three-stage sealing are identical, the total resistance equivalent is

$$h_{total} = \frac{h_{1-2}}{2} + \frac{h_{1-2}}{2} + h = 2\,h = 256 \frac{\nu\,l}{\pi\,d^4 g}\ Q' \tag{9}$$

This loss is also found in the pressure drop across the seal

$$h_{total} = \frac{\Delta p}{\rho\,g} \tag{10}$$

$$\frac{\Delta p}{\rho\,g} = 256 \frac{\nu\,l}{\pi\,d^4 g}\ Q' \tag{11}$$

The flow through the seal is

$$Q' = \frac{\Delta p \, \pi \, d^4}{256 \, \nu \, l \, \rho} \tag{12}$$

Replacing the initial values in the formula results the value of the flow through the seal

$$Q' = 0.055 \ \cdot 10^{-3} \, m^3/s$$

The flow enter into the pump

$$Q'' = Q_{total} - Q' = \ 0.195 \ \cdot 10^{-3} \, m^3/s$$

3.4 Electrical model

Solving the circuit is made using the two Kirchhoff's laws, algebraic sum of currents in a circuit node and algebraic sum of all voltage drop in a circuit loop, which are applied to the appropriate equivalent electrical circuit (figure 2), respectively using the continuity equation and Bernoulli's equation for the flow and pressure drop in a circuit equivalent loop [1].

In this model has not been used SimHydraulics library. We used Simulink Library Browser but SimRF/SimPowerSystem library that contains sub-libraries that Circuit Envelope (Elements and Sources)/ Elements and Electrical Sources [1].

In figure 3, at circuit exit, there is a capacitor placed in parallel with the resistance, so there are two branches: one with the resistance in which the current circulating normal (D_2O flows to the D_2O Storage Tank), and another branch with the capacitor with no current circulation (no D_2O flow). If the pressure drop (respectively voltage drop) across last stage is normal 33 bars to 1 bar, the capacitor isolates the circuit and there is no current circulation (no D_2O flow) through this branch.

But if one of the seal stages breaks down, the pressure inside the third cavity increases, so the pressure drop across the last stage increases, this means that the equivalent voltage drops across the capacitors increase, leading to capacitor breakdown and resulting current circulation through this branch (D_2O flows to the D_2O Collection Tank).

The operation is based on the application of Kirchhoff laws, as follows (figure 3):

Kirchhoff's first law

$$Q = Q_1 + Q_2 = Q_3 + Q_4 = Q_5 + Q_6 \tag{13}$$

The second Kirchhoff's law has the same form for the two parallel resistances groups

$$h_1 = R_1 {Q_1}^2 + R_2 {Q_2}^2 \tag{14}$$

and for the all three seals

$$h_{total} = \frac{h_1}{2} + \frac{h_1}{2} + h_1 \quad (15)$$

the same with equation (9).

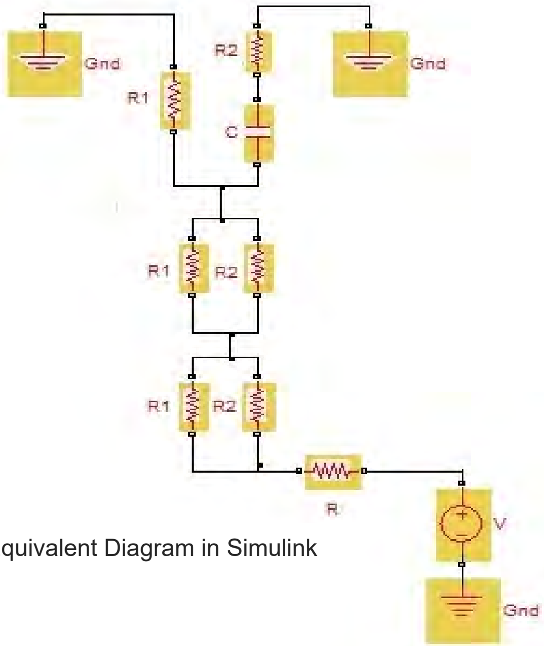

Fig. 2 Equivalent Diagram in Simulink

Based on previous relationships, dependencies between flow and seals resistance can be simulated on the computer for various factors and values of Q, R, C and h.

4. Conclusions

■ Hydraulic calculation leads to results similar to those known from practical measurements made on gland seal cooling circuit of primary heat transport pumps of CANDU nuclear power plants. This result confirms the validity and correctness of the assumptions adopted.

■ Electrical model facilitates simulation of the mechanical seals operation, using a simple schema and avoiding any types of risks.

■ On this basis, can be computed nomograms, in order to facilitate the studies forecast of the operating mode of the primary heat transport pumps gland seal cooling system.

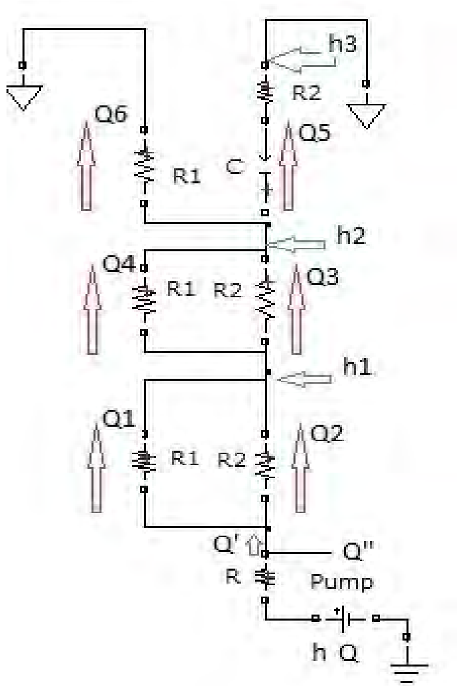

Fig. 3 Primary Heat Transport System Pumps Seal Simulation

REFERENCES

[1] Popescu, M.C., *Modeling and simulation of processes* (Romanian language), Universitatea din Craiova Printing house, Craiova, 2008.

[2] * * * CNE CERNAVODA, *Basic training manual "Heat transport pumps gland seal cooling system ".*

[3] * * * CNE CERNAVODA, *Operational flowsheet "Heat transport pumps gland seal cooling system".*

[4] * * * CNE CERNAVODA, *Design Manual "Gland seal circuit cooling system ".*

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