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## The design of 25kw class hydraulic turbine generator by using CAE

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Abstract. CAE(computer aided engineering) had been used in order to build/ design small and medium size generator. The whole process was organized with Electromagnetic analysis, thermal-hydraulic analysis, structural analysis and test result analysis. Results of output, efficiency, and temperature which are suitable for specification of generator can be predicted by using Electromagnetic analysis. Thermal-hydraulic analysis enable me to predict the internal temperature of generator whether to maintain below the critical temperature. The analysis safety was verified with structural analysis, and all of safety ratio was above 1. In comparison test results with CAE results, the maximum error rate was below 6% that shows high accuracy.

#### **1. Introduction**

Some of countries with relatively scant chemical energy resources need to import most of it from other countries. In terms of those countries, it is very important to reduce reliance on foreign sources of energy and make the most of domestic sources of energy. Recently, find solutions to meditate fine dust problem. Imprudent usage of coal and environmental regulation. Especially in energy industry, renewable energy. Among renewable energy, hydraulic energy is fluid machinery that converts from water potential into mechanical energy. Compare to other renewable energy, hydraulic energy has consistent output. However, small and medium size hydraulic turbine relies heavily on import. In addition, technology on hydraulic turbine only remains in benchmarking level. In this paper, I'd like to suggest some methods of building generator by establishing small and medium size generator design process.

#### 2. Design specification and design process

Figure 1 and Table 1 illustrate generator design specification and design process.

Design production process build early design of generator that meets specification shown in the Table 1. Then, it verifies output of generator by using electromagnetic analysis. Generator part design is followed after that and it evaluate safety factor through thermal-hydraulic analysis and structure analysis in accordance with generator part. After predicting performance by using CAE, verifies the performance through generator production and tests.

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Description	Value	Unit
Rotating speed	800	Rpm
Voltage	200	V
Power	25	kW
Rotating speed	800	Rpm

Figure 1. Design process of generator.

#### 3. Electromagnetic analysis

#### 3.1. Geometry for Electromagnetic analysis

The overall design was based on generator specification, and Table 2 illustrates designed generator specification. It added magnet holder and stopper to prevent breakaway of magnet when the rotor is rotated with a magnet on its surface. The output was verified on the electromagnetic analysis data from ANSYS Maxwell.

Table 2.	Generator	design.
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Description	Value	
Stator Diameter [mm]	550	
Rotor Diameter [mm]	421	
Pole / Slot	32 / 102	
Pole efficiency	0.875	



Figure 2. Magnet holder and Stopper.

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#### 3.2. Boundary condition for Electromagnetic analysis

ANSYS Maxwell was used for magnetic interpretation. Explanation of boundary condition is illustrated in Table 3.

Description	Value
Solver	Transient
Rotation Speed [rpm]	800
Excitation	External circuit

#### **Table 3.** Boundary condition of electromagnetic analysis.

#### 3.3. Results of electromagnetic analysis

Table 4 shows result of electromagnetic analysis. The power was 26.8 kW, which is 7% higher than 25 kW and Efficiency is predicted approximately 93% when the mechanical loss is assumed 3% of output.

Table 4	. Results	of	electromagnetic	analysis.
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Description	Result	Unit
Line to line voltage	212	V
Current	72.5	А
Power	26.8	kW
Efficiency (machine loss included)	93.4	%



Figure 3. Contour of flux density and loss.



Figure 4. Line to line voltage and current.

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#### 4. Thermal-hydraulic analysis

#### 4.1. Geometry for thermal-hydraulic analysis

ANSYS CFX was used for Thermal-hydraulic analysis. Under rated operating conditions, floating analysis was used in order to predict generator temperature rise. Figure 5 shows generator model. Fan was installed in the motor shaft for increasing Cooling effects. In order to Reduce mesh elements, and resolution time, analytical model was analyzed with a 1/6 cycle model.



Figure 5. Geometry of Generator.

#### 4.2. Grid system for Thermal-hydraulic analysis

In order to maintain shape, Tetra and Prism was used in shapes that contain complex and curves. Also, node number in grid system was generated with a high quality grid. The number of node is made up of dense entire part of rotor, and fan location.



Figure 6. Grid system.

#### 4.3. Boundary condition for Thermal-hydraulic analysis

The heat dissipated by the magnetic field analysis for the stator core, coil, magnet, and rotor was used as the heat source. Also, complex heat transfer analysis was performed to analyze the fluid and solid models at the same time. In order to perform efficient analysis, steady state analysis was performed with a 1/6 rotation period model. Since the external flow is in a natural standby state, the opening condition is applied. Details of boundary condition are shown in Figure7 and Table 5.

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Figure 7. Boundary condition of Heat source.

**Table 5**. Boundary condition of Thermal-hydraulic analysis.

Description	Value
Solver	Steady state
Rotation Speed [rpm]	800
Turbulence model	s.s.t
Heat source	Electromagnetic field result
External boundary	Opening condition

#### 4.4. Result of Thermal-hydraulic analysis

Figure 8 shows the internal flow distribution of hydro turbine generator. As, external air flows into generator in the axial directions, it flows quickly through the generator. Heat generation part was cooled by the air flows. Figure 9 shows the internal temperature distributions, and the maximum coil temperature was estimated at maximum 45.4 °C. Table 7 shows the critical temperature of the insulator of type f is 105 °C. it is a key point to select a cooling fan that coil does not exceed the critical temperature. Table 7 shows the temperature result of generator parts. it is considered that there is no significant influence on generator performances.



Figure 8. Internal velocity distribution of generator.



Figure 9. Internal temperature distribution of generator.

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Insulator type	Standard temp. [°C]	Description	Max Temp. [°C]
130(B)	95	Stator coil	45.4
155(F)	115	Stator core	44.9
190(U)	125	Magnet	29.2
180(H)	<u>(1)</u>	Rotor	27.3
		Core holder	41.8
		Housing	403.5
		Bearing	26.3
		Shaft	26.1

Table 6. Critical temperature of Insulator type.

**Table 7.** Temperature result of generatorparts.

#### 5. Structural analysis

#### 5.1. FE model for structural analysis

ANSYS workbench was used for structural analysis The rotor of generator should be analysed for safety against torque and centrifugal force. In this model, the rotor and shaft shall be safe against the applied torque, and the magnet holder should be held for the load that occurs when the magnet break away from the holder by centrifugal force. Figure 10 shows the FE model for the structural analysis, and FE model is modelled with SOLID187(20nodes) and is shown in Figure 10.



Figure 10. Element model of structural analysis.

**Table 8**. Structural analysis grid information.

Description	Elements	Nodes
Shaft & Rotor	184,338	605,162
Magnet Holder	11,623	62,191

#### 5.2. Boundary condition for structural analysis

Generally, the design torque depending on the type and condition of equipment is 1 to 3 times the rated torque. In this analysis, 5 times rated torque is used for conservative evaluation. Although the rated rotated rotation speed of generator is 800rpm, the rotational speed of the generator can be increased to 2 times under no-load condition. Therefore, the structure was analysed at 1,600 rpm. The boundary conditions are shown in Figure 11 and Table 9.

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(a) Shaft & Rotor. (b) Magnet Holder.

Figure 11. Boundary condition for structural analysis.

#### Table 9. Load condition for structural analysis.

Description	Load	unit
Shaft	1,650	N.m
Rotor	1,650	N.m
Magnet Holder (Case 1)	800	rpm
Magnet Holder (Case 2)	1600	rpm

#### 5.3. Result of structural analysis

The analysis results are as shown in the Figure 12 and Table 10. The safety factors for the stress results are over 1.0. That is, the stress of the structure should not exceed the yield. The result of rotor under the torque load is that the maximum stress occurs at the thinnest region of the rotor body and the safety factor is about 1.6. Because the load is overloaded five times with the rated torque, so the rotor is safe against the torque load.

For the magnet holder, the safety factor of 4.5 is at the rated speed case(case 1) and is 1.1 at the no load condition (Case 2).



(a) Shaft & Rotor . (b) Magnet Holder.

Figure 12. Stress of shaft, rotor and magnet holder.

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Description	Stress [MPa]	Yield strength [MPa]	Safety Factor
Shaft	91.3	343	3.7
Rotor	146.5	245	1.6
Magnet Holder (Case 1)	54.4	245	4.5
Magnet Holder (Case 2)	220.2	245	1.1

**Table 10.** Result of structural analysis.

\* Safety factor = Yield strength / Stress result from FEA

#### 6. Generator Experiment

Figure 13 shows the generator load test environment. The test was carried out in a KTL (Korea Testing Laboratory). The test results are shown in Table 10. In the initial operation, the output was 26kw which is identical as the analysis results. The output decreases to 25kw after temperature saturation. In this design, the analysis was carried out at room temperature.



Figure 13. Generator load test environment.

Test results and analysis results are shown in Table 11 below. The error rate between the analysis result and test result was low and in the case of efficiency, the error was 6%, and the temperature shows within 5% error. The dimension and boundary condition of the electromagnetic analysis, thermal-hydraulic analysis and structural analysis are same as in the experiment.

**Table 11.** Comparison of analysis result and experiment result.

Description	Analysis result	Experiment result	Error [%]
Rotating speed [rpm]	800	800	0
Coil Temperature [°C]	45.4	48	5.4
Line to Line Voltage [V]	213.4	208	2.5
Electric current [A]	72.5	71	2.0
Power [kW]	26.8	26.8	0
Efficiency (machine loss included) [%]	93.4	90	3.42

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#### 7. Conclusion

In this study, the whole process was established by using CAE from design to manufacture for 25kw generator design process. 25KW output and 93.4% efficiency generator were designed through the electromagnetic analysis. The performance of the generator cooling fan and the maximum temperature of the coil were confirmed with using the thermal-hydraulic analysis. Structural analysis showed that the rotor components obtained a safety factor of 1.6, even though the overload was five times higher than the rated torque. In the case of magnet holders, structural stability verification has been completed while maintaining safety factor of 4.5. The final experiment shows that the error of output, efficiency and temperature of the generator are up to 6%. The overall result is reliable. Also, it is possible to predict other performance and defects by using same technique.

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