Gearbox losses measurement

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Abstract

Many low head units with Kaplan turbines are equipped by gearbox. Determination of turbine efficiency is based on the electrical output of the generator and determination of its losses, as well as losses in the gearbox in addition to flow and head measurements. Generator losses or efficiency are usually well known because of generator acceptance tests or exact calculation of particular losses. But the great unknown remains usually the gearbox efficiency / losses. Only one value of gearbox efficiency for nominal output is often stated by the supplier. However, this information is insufficient for guarantee measurement.
OSC Company has lot of experience with calorimetric measurement of bearing losses and generator losses according to standard IEC EN 60034-2-2. The same principles can be used to measure gearbox efficiency. We applied this methodology on gearbox tests with nominal transmitted power 3.5 MW. Three gearboxes were tested under normal operation conditions.

1. Introduction

The units at HPP Štětí, river Vltava, are equipped with three-shaft gearboxes that increase the speed of the turbine for the generator. The gearboxes were flooded by high water during power plant construction and visible changes appeared on the gearing. Based on the customer's request, the losses of gearboxes were measured using the calorimetric method before their replacement. The losses were measured in accordance with the recommendation in the ČSN EN 60034-2-2 standard [2] for generator losses determination.
The heat losses of the gearboxes before replacement were measured on TG1 during the GM in autumn of 2014.
After replacing the original gearboxes with Wikov gearboxes, an identical measurement was carried out on the TG1 gearbox in January 2016.

2. Principle of calorimetric measurement

The total generator or gearbox losses P_{irs} are divided into two groups:

$$P_{irs} = P_{irs,1} + P_{irs,2} \tag{1}$$

where:

$P_{irs,1}$ [kW] = heat power led out by the cooling medium (here by oil)
$P_{irs,2}$ [kW] = heat power dissipated by radiation from the gearbox surface

2.1. Heat power $P_{irs,1}$ led out by the coolant

The total warming of the coolant was measured after reaching temperature stability. During the measurement on the original TG1 gearbox, the valve to cooler of the heat exchanger of the gearbox oil was switched cyclically to keep the oil temperature in the desired range, see Fig. 1. On the TG2 set, due to thermostat malfunctions, the cooler valve did not switch, therefore the input and output temperature was higher compared to TG1 – see Fig. 2.
The thermal power dissipated in the coolant is calculated according to the following relationship:

$$P_{irs,1} = c_p \cdot Q \cdot \rho \cdot \Delta T_{LIQ} \tag{2}$$

where:

Q [m^3/s] = coolant volumetric flow rate
ΔT_{LIQ} [°C] = heating of the coolant

$$\Delta T_{LIQ} = t_{outav} - t_{inav} \tag{3}$$

t_{outav}, t_{inav} [°C] = mean value of input and output temperatures t_{out}, t_{in} during the measurement period

The parameters of Shell Omala-S4-GX-320 oil were used for the calculation:

c_p [kJ/(kg·K)] = specific heat capacity of the coolant, $c_p = 2.00\ kJ\cdot(kg\cdot K)^{-1}$
ρ [kg/m^3] = coolant density, $\rho = 883.0\ kg\cdot m^{-3}$

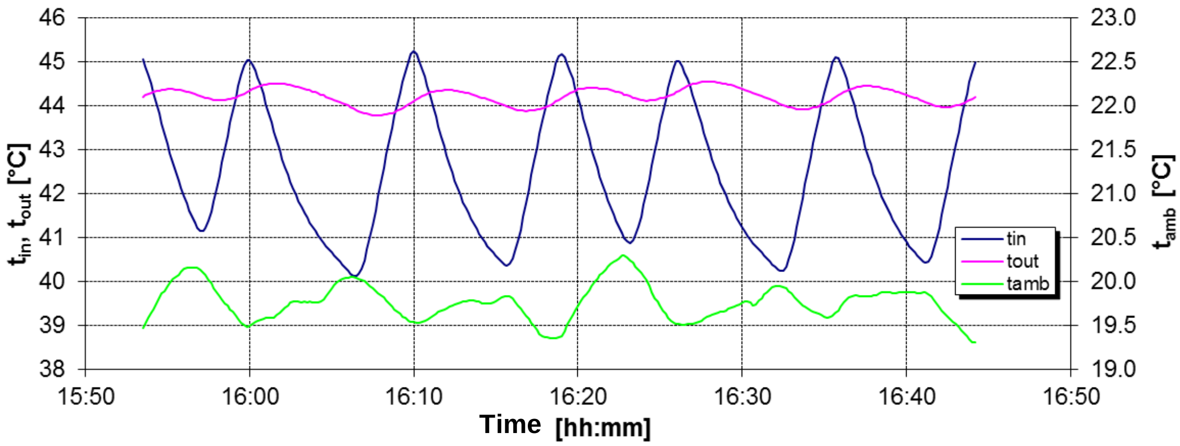

Fig. 1: Record of cooling oil input/output and ambient temperatures on TG1 with original gearbox

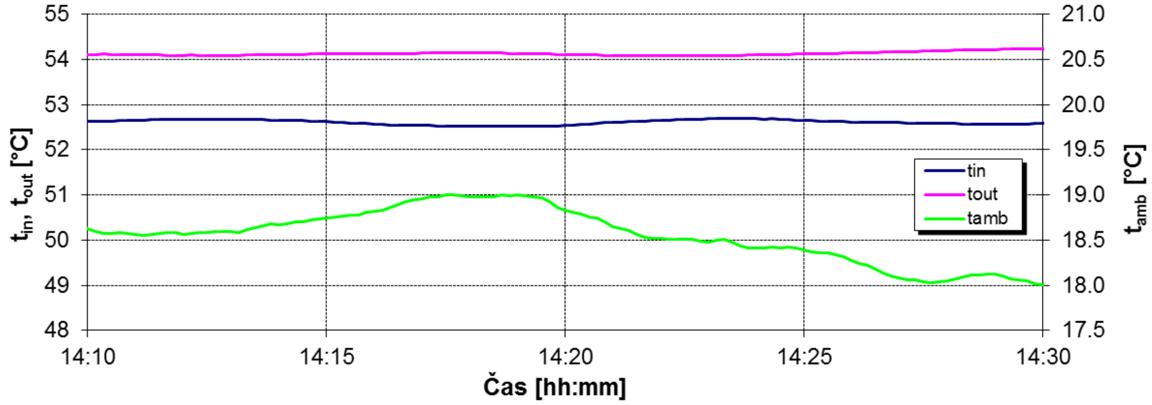

Fig. 2: Record of cooling oil input/output and ambient temperatures on TG2 with original gearbox

Used instrumentation:

- Coolant input and output temperatures were measured using Pt100 thermometers. Zero of temperature difference was adjusted before start of test in a similar way like by thermodynamic test.
- The nominal flow rate of coolers' gear pump was considered for further calculation.

2.2. Heat power dissipated by radiation from the gearbox surface - $P_{irs,2}$

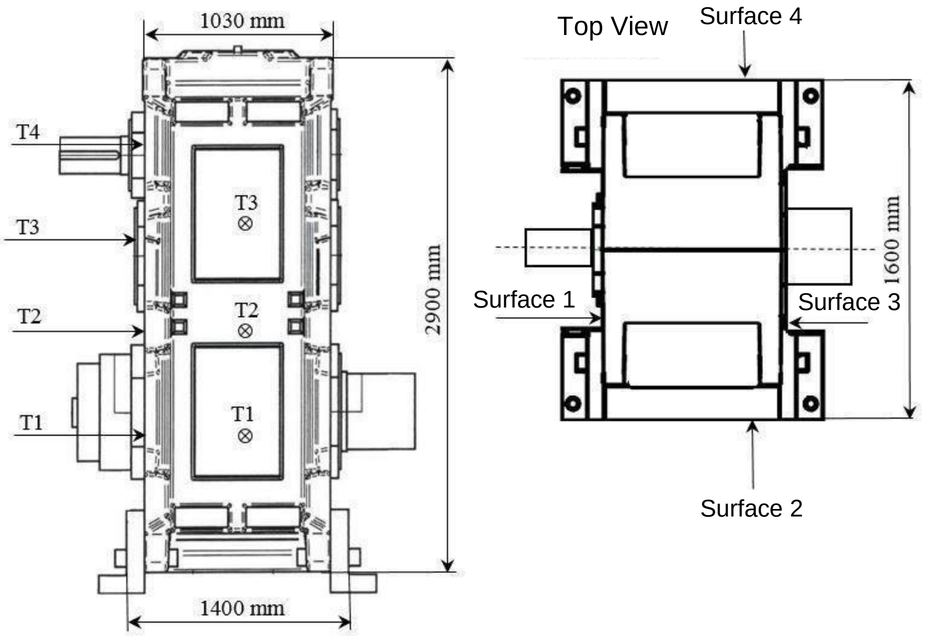

Fig. 3: Sketch of the original gearbox

The natural convection of the gearbox located in the PIT turbine was considered in the radiation calculation:

$$P_{irs,2} = h \cdot A \cdot \Delta T_{SUR} \tag{4}$$

where:

h [$W \cdot m^{-2} \cdot K^{-1}$] = Heat transfer coefficient for losses radiated from surfaces which are in contact with air
The recommended value according to [2] is h = 20 $W \cdot m^{-2} \cdot K^{-1}$ for natural convection
The coefficient value for rotating output shaft based on peripheral speed is about 35 $W \cdot m^{-2} \cdot K^{-1}$ (forced convection)

A [m^2] = Total surface area of the gearbox

ΔT_{SUR} [°C] = The temperature difference between the average surface temperature and the ambient temperature

$$\Delta T_{SUR} = t_{sur\ av} - t_{amb} \tag{5}$$

The basic dimensions of the original gearbox measured on site are shown in the Fig. 3. The surface of the gearbox is indented and the temperature is irregularly distributed, therefore the number of points at which the temperature was measured was determined for the calculation to obtain the actual average temperature.

2.3. Gearbox efficiency

The gearbox efficiency calculation based on the evaluated partial losses and active power according to the following formula:

$$\eta_{GB\_meas} = \frac{P_G}{P_G + P_{irs}} \tag{6}$$

where:

P_{irs} [kW] = Σ of particular losses ($P_{irs,1}$ + Σ $P_{irs,2}$)

P_G [kW] = Generator input power (on the shaft)

$$P_G = \frac{P_a}{\eta_G} \tag{7}$$

P_a [kW] = Generator active output

η_G [-] = Generator efficiency (as function of active power)

Used instrumentation:

- The surface temperature was measured with combined infrared/contact thermometer Testo 845.
- Ambient temperature in the PIT was continuously measured with Pt 100 thermometer.

3. Results

Measured and calculated values from efficiency tests of original gearboxes are presented in Tab. 1 and in Fig. 4. Although for TG1 and TG2 there is a different distribution of thermal power between the radiation and the cooling medium due to the significantly higher temperature of the TG2 gearbox due to the failure of the cooler, the resulting efficiencies are similar. The big difference between guaranteed and measured efficiency is surprising. The reason is unknown. That may be guaranteed values determined as computational efficiency with a certain margin or a large systematic measurement error. Since the total loss would have to be doubled to achieve guaranteed efficiency, a combination of both causes is most likely.

The measured efficiency of new installed gearbox is also presented in Fig. 4. Due to minimal operation restrictions, only two operating points were measured.

Tab. 1: Losses and efficiencies of original gearboxes

Unit	P_a	t_{in}	t_{out}	t_{amb}	$t_{sur\ mean}$	$P_{irs,1}$	$P_{irs,2}$	P_{irs}	Z_{Gen}	P_G	$\eta_{GB\ meas}$
	kW	°C	°C	°C	°C	kW	kW	kW	kW	kW	%
TG1	1580	42.1	43.8	18.2	42.5	9.0	15.3	24.3	48	1628	98.5
	2184	43.3	45.3	19.7		10.9	13.3	24.2	55	2239	98.9
	2300	42.7	44.7	18.5		11.2	14.0	25.2	56	2356	98.9
	2583	38.9	43.2	18.4		23.2	14.1	37.3	61	2644	98.6
TG2	1030	51.4	52.5	18.2	56.2	6.0	23.3	29.3	45	1075	97.3
	2150	52.3	53.5	17.7	55.7	6.7	23.8	30.5	54	2204	98.6
	2502	52.6	54.1	18.6		8.3	23.3	31.6	59	2561	98.8
	2795	52.4	54.6	17.6		11.9	23.9	35.8	64	2859	98.7

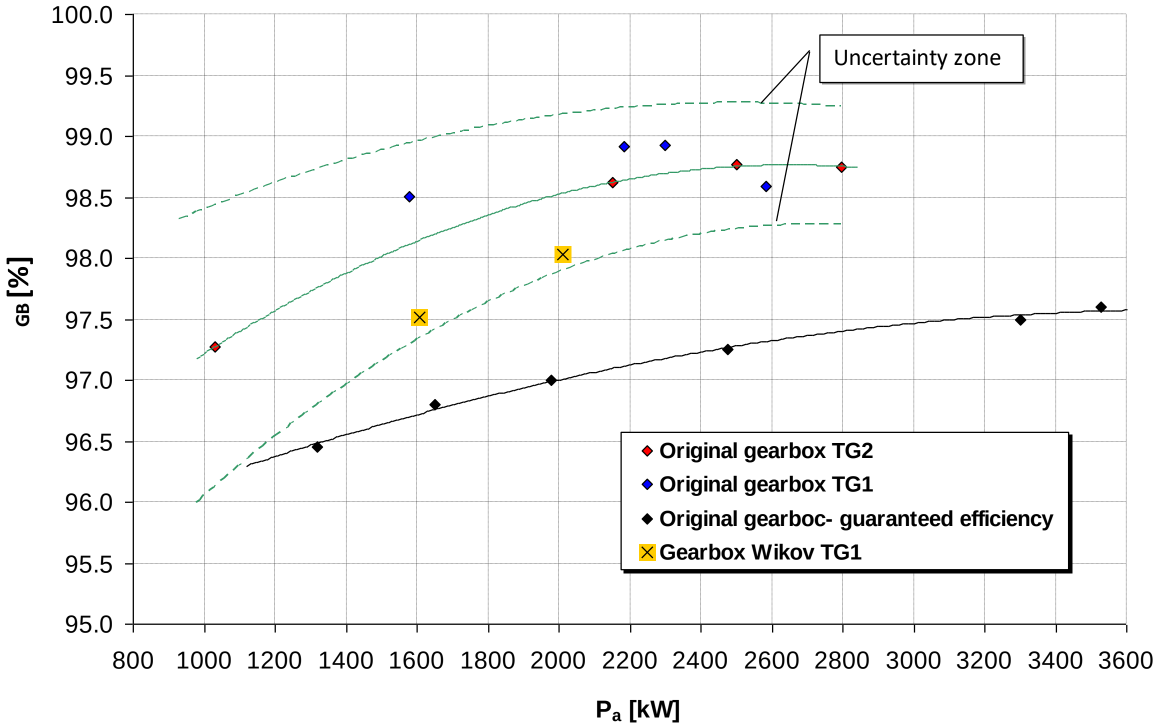

Fig. 4: Efficiency of original and new gearboxes

4. Conclusion

Experience with field measurement of gearbox efficiency using a methodology designed for generators can be summarized as follows:

- The calorimetric test is the only method that can be used to field measurement of gearbox efficiency without major modifications of the installed equipment.
- For generators, more than 90% of the total losses are dissipated by the cooling medium, where the heat output can be easily and accurately measured. Less than 10% of the total losses are left to radiation and other residual heat flows.
- In gearboxes, the distribution of heat flows is different. The radiation as well as convection have similar weight. The relative radiation uncertainty was considered to be around 50% for the point measurement used. The uncertainty of heat transfer through the coolant was negatively affected by the two-state principle of temperature regulation.

Suggestions for improving the calorimetric measurement of transmissions are as follows

- Using a longer recording time of temperatures and, eventually, of flow rate in the case of two-state temperature regulation of the gearbox under steady state.
- Using an infrared camera to scan the gearbox surface and then digitally processing the image to determine the radiated heat output.

5. References

[1] Ševčík P.: *Gearboxes efficiency at HPP Štětí, Calorimetric test*, Technical report TZ 2160/3000, OSC 2016.

[2] IEC 60034-2-2: *Rotating electrical machines - Part 2-2: Specific methods for determining separate losses of large machines from tests - Supplement to IEC 60034-2-1*, 2010.