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DEVELOPMENT & RESEARCH OF DOUBLE LOOP THERMOSYPHON AIR-AIR COOLER FOR WIND POWER GENERATOR

GuoDong Lu*, Haimin Shi, Jianwei Zhou
*Author for correspondence
Hangzhou Yinlun Technology & Engineering Co., Ltd.,
Hangzhou 310013,
China,
E-mail: luguodong@yinlun.cn

ABSTRACT

Wind energy is well recognized as the nearest commercialized renewable energy technologies besides the water resource, it has high priority by governments, is developing rapidly worldwide. In the field of wind power, single megawatt wind power unit is becoming the mainstream of technology development and market demand [1]. On the one hand it is needed to optimize the generator structure to reduce heat generation [2], more importantly, efficient cooling system is needed to protect the generator [3].

Air-water cooled and air-air cooled are the main cooling mode for wind power generator coolers. For the air cooled type, most of the current application has simple smooth tube bundle structure, it is larger in size and heavier in weight, it has higher energy consumption and sometimes unable to meet the cooling requirements during hot summer. Lightweight design is the trends, a new type thermosyphon air cooled heat exchanger is developed, compared with the conventional one, preliminary studies indicate that it is about 29% smaller in size, 13.4% lighter in weight, 16.3% saved in energy consumption and 14.6% improved in cooling capacity.

NOMENCLATURE

Q	[W]	Heat transfer rate
$\dot{m}$	[kg/h]	Mass flow rate
α_{tol}	[W/(m^2.K)]	Overall heat transfer coefficient
φ	[-]	Correction factor
Nu	[-]	Nusselt number
Eu	[-]	Euler number
Re	[-]	Reynolds number
Pr	[-]	Prandtl number
$\Delta t_{\max}$	[℃]	Maximum temperature difference
$\Delta t_{\min}$	[℃]	Minimum temperature difference
Δt_m	[℃]	Logarithmic mean temperature difference
D	[m]	Hydraulic diameter
λ	[W/(m.K)]	Thermal conductivity of the airflow
$u_{\max}$	[kg/(m^2.h)]	Maximum mass velocity
ρ	[kg/m^3]	Density
s	[m]	Fin spacing
h_f	[m]	Fin height
t_f	[m]	Fin thickness
s_1	[m]	Longitudinal tube pitch
T_{in}	[℃]	Inlet temperature of flow fluid
T_{out}	[℃]	Out temperature of flow fluid
$T_{h,in}$	[℃]	Inlet temperature of hot air
$T_{c,in}$	[℃]	Inlet temperature of cooling air
q_{act}	[kW]	Actual heat transfer rate
$q_{\max}$	[kW]	Maximum heat transfer rate

Subscripts

max	Maximum
min	Minimum
m	Mean
f	Fin
h	Hot air
c	Cooling air
in	Inlet
out	Outlet
o	Outside

1.INTRODUCTION

As oil and coal resources dwindling, the world reach a consensus on energy conservation. New energy such as wind, solar and nuclear energy, etc. are getting more and more applications.

Fig.1 shows the wind power cabin layout about 90m above the ground, the generator 4 and the air-air cooler 5 is installed in the rear cabin. Ventilation is important to ensure the normal operation of the generator. Fig.2 shows the working principle of the current air-air cooling mode. Cooling air will go through the tubes and hot air will flow outside the tubes. As the cooling parts, smooth tube bundle has large volume, higher air flow resistance inside the generator cabin, and this structure is easy lead to uneven air flow inside the power cabin, maybe these are the main defects of the current air-air cooler.

Thermosyphon is a good heat exchanger component, it can quickly transfer heat from one space to another space. Thermosyphon air-air cooler (TAAC) is a new heat exchanger applied on wind power generator.

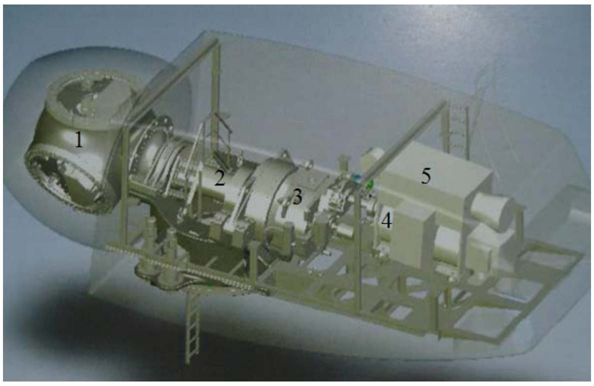


Fig. 1 Layout of the wind power cabin

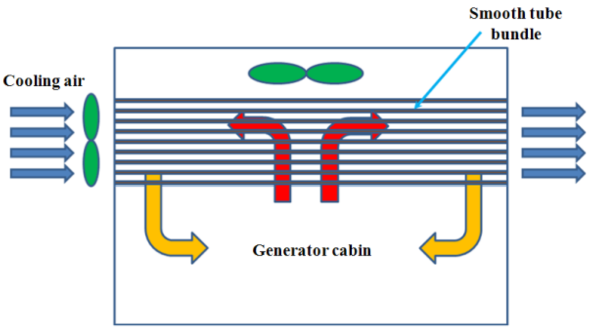


Fig. 2 Working principle of current heat exchanger

2. DESIGN SCHEME

2.1. DESIGN REQUIREMENT

The stator and shaft of the generator are the hottest parts, need to be cooled down in time. For the generator, the maximum working air temperature inside the power cabin is about 150℃, 105℃ higher than the maximum ambient 45℃. The rejection capacity required is about 60kW under this condition.

Because of the limited cooling capacity and the high cost of the current heat exchanger, the new heat exchanger must has competitive cost, size, weight, energy consumption and enough rejection capacity.

2.2. DESIGN SCHEME

In order to enhance the air circulation inside the power cabin, the driving force from centrifugal force generated by high-speed rotation of the rotor is not enough. New driving fan must be added to overcome the internal resistance, it can help the air circulation more uniform. Generally, the fan motor has limited capacity to withstand high temperatures, so the fan with external motor is more suitable for this application.

The selected thermosyphon is gravity-assisted and without wick inside, the working fluid is water. Single thermosyphon is 780mm long, with continual spiral fin outside. The working principle is shown in Fig. 3. The lower half of the TAAC joins together with the generator cabin to form a closed space cabin. For the generator cabin, the driving fan and the rotor play a dynamic role to form two circulation, the small cycle is the main loop, most air will flow through the surface of the generator shaft and the surface of the rotor in this loop, the other part air will go through till the end of the shaft, then flow upward and round the main loop. Hot air transfers the heat to the thermosyphon bundle, then back to the fan to complete a work cycle. On the cooling side, the cooling air flow across the top half bundle of the TAAC and take the heat away.

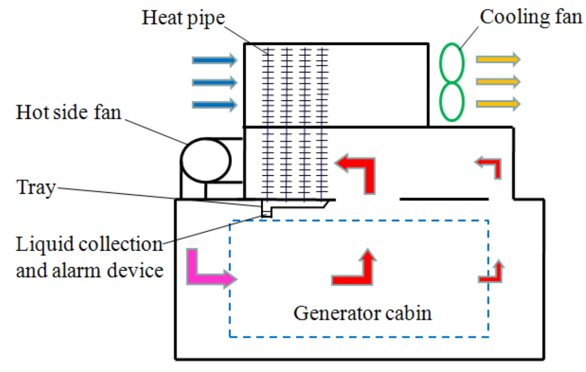


Fig. 3 Working principle of the TAAC

2.3. STRUCTURAL FEATURES

The new concept of double loop air flow is introduced into the TAAC, it reasonably split the hot air flow inside the cabin into two loop.

There is a tray installed under the thermosyphon bundle, it can collect the accidental dropping water comes from the possible thermosyphon leakage and then collect it together, then the alarm device will work once the water reaches a certain level.

Also there is a powdered desiccant installed inside the generator cabin to keep dry.

2.4. SMALL SIZE SAMPLE

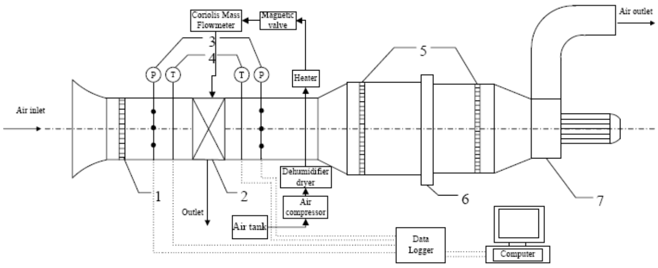

a. In-line arrangement b. In staggered arrangement
Fig. 4 Small size samples in line & staggered arrangement

In order to reduce the development cost and the risk, a small size heat exchanger sample is fabricated, then a series performance tests are carried out to check whether thermosyphon bundles in-line or staggered arrangement can meet the requirement.

Fig. 4 shows the samples with 16 thermosyphon tubes in different arrangement. The parameter of the sample thermosyphon tube is same with the full size prototype, as introduced in 2.1.

3.WIND TUNNEL EXPERIMENTAL RESEARCH

3.1. WIND TUNNEL TEST RIG



1 honey cone straightener 2 test unit 3 pressure tap 4 temperature measuring station 5 setting means 6 multiple nozzle plate 7 variable exhaust fan system

Fig. 5 Wind tunnel test rig[9]

The schematic diagram of the wind tunnel test rig is shown in Fig. 5. It consists of four parts as follows [9]: a suction type wind tunnel, hot air circulation system, control system, and a data acquisition system. The wind tunnel is in suck mode driven by a centrifugal fan. The hot air has been compressed and dehumidifier dried before heated. In order to minimize heat loss to the surroundings, the tunnel is insulated with a 50 mm thick glass wool. The inlet and outlet temperature of the cooling air side are measured by two T-type thermocouple nets. The inlet measuring net consists of 10 thermocouples and the outlet net contains of 20 thermocouples. These thermocouples are pre-calibrated with an accuracy of 0.1℃. The hot air is heated by a electric heater with a capacity of 100 kW. The inlet and outlet temperature sensor of hot air are measured by a temperature monitoring system with two pre-calibrated RTDs (Pt-100) with an accuracy of 0.1℃. The air pressure drop across the TAAC and the nozzles are measured by precision differential pressure transducers with an accuracy of 0.4% and 0.25%, respectively. The hot compressed air is measured by coriolis flow meter while the cool air flow rate is measured by a multiple nozzle code test rig based on the ISO 5167 standard. In order to ensure accuracy, the wind tunnel test rig had been calibrated and the heat balance was maintained between ±5%.

3.2. TEST CONDITION

Hot air flow (kg/h): 544, 1088, 1587, 1814

Cooling air speed (m/s): 1~7

Temperature difference between hot air inlet and cooling air inlet (℃): 30, 45, 60

3.3. DATA REDUCTION

The minimum heat transfer rate needed to be dissipated from the hot compressed air was calculated as follow:

$$Q_{\min} = c_p q_m (T_{in} - T_{out}) \tag{1}$$

Where c_p is the specific heat of the ambient air; q_m is the mass flow rate; T_{in} is the inlet temperature of flow fluid; T_{out} is the outlet temperature of flow fluid.

In order to determine the number of thermosyphons, it is necessary to calculate the heat transfer rate of single thermosyphon at different conditions. The overall thermal resistance of the thermosyphon is given as follow.

$$R_{\text{tol}} = R_{\text{fin,evap}} + R_{\text{w,evap}} + R_{\text{ff,evap}} + R_{\text{ff,cond}} + R_{\text{fin,cond}} + R_{\text{w,cond}} \tag{2}$$

The total heat transfer coefficient is determined by

$$\alpha_{\text{tol}} = \frac{1}{R_{\text{tol}} A_{\text{fin}}} \tag{3}$$

Where A_{fin} is the whole fin surface area, R_{tol} is the total thermal resistance.

The average heat transfer rate of single thermosyphon is given as follow:

$$Q = \alpha_{\text{tol}} A_{fin} \Delta t_{\text{m}} \tag{4}$$

Where Δt_m is the logarithmic mean temperature difference.

A Nusselt number for heat transfer from the air to the fins is given as follow.

$$Nu = \alpha_{fin} D / \lambda \tag{5}$$

Where D is the hydraulic diameter, λ is the thermal conductivity of the airflow, the Reynolds number is also based on the hydraulic diameter.

Briggs and Young [10] provides the following empirical equation:

$$Nu = 0.134 \,\text{Re}^{0.681} \,\text{Pr}^{1/3} (s/h_f)^{0.2} (s/t_f)^{0.1134} \tag{6}$$

Where s, h_f and t_f is the spacing, height and thickness of the fin.

A TAAC consisting of 60 individual gravity-assisted wickless thermosyphons was designed as shown in Fig. 9. The thermosyphons were arranged in four rows and in staggered equilateral triangle arrangement.

K.K.Robinson and D.E.Briggs gives the relational resistance as follow:

$$\Delta P = f_s \frac{nG_{\max}^2}{2\rho} \tag{7}$$

Where friction coefficient

$$f_s = 37.86 \left(\frac{d_o G_{\max}}{\mu} \right)^{-0.316} \left(\frac{s_1}{d_r} \right)^{-0.927} \left(\frac{s_1}{s_3} \right)^{0.515} \tag{8}$$

Where s_3 — Bundles arranged in a triangle, Triangle hypotenuse length, m

d_r — fin root diameter, m

The condition of the correlation is:

Re = 2000 ~ 5000

$s_1 / d_r = 1.8 \sim 4.6$

$s_1 and s_2 = 42.85 \sim 114.3mm$

$d_o = 40 \sim 65mm$

$s = 3.11 \sim 4.03$

3.4. DATA ANALYSIS

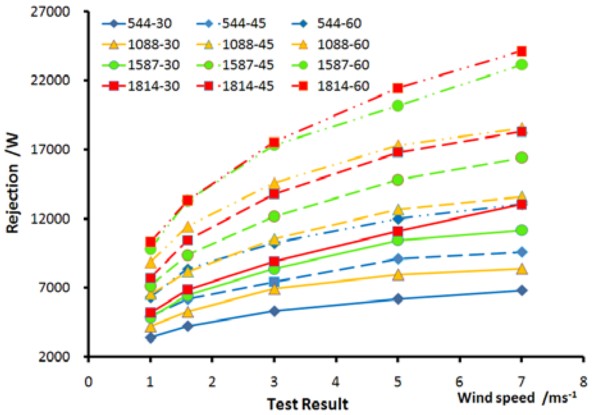


Fig. 6-1 Small size sample performance-rejection

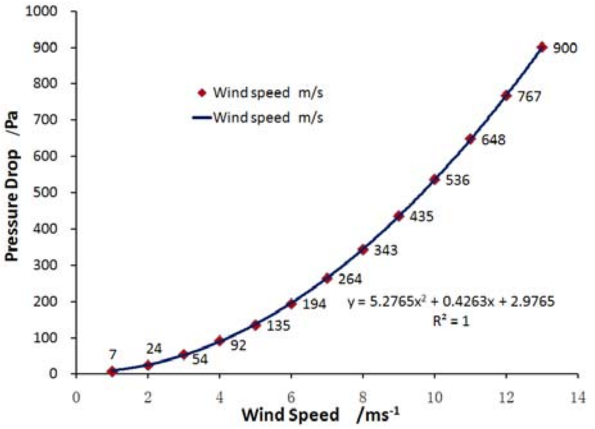


Fig. 6-2 Small size sample performance-pressure drop

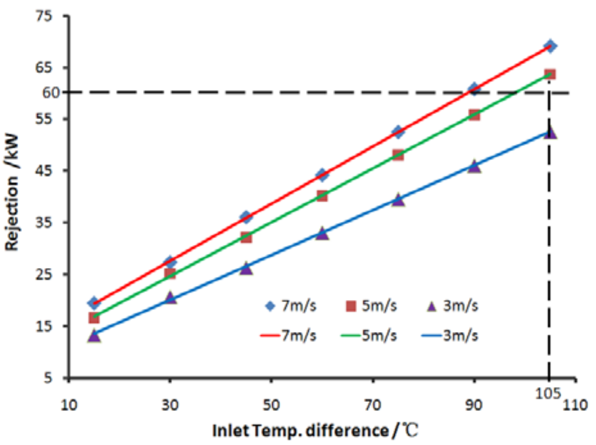


Figure 7 Full size TAAC performance prediction

For the size limit, current wind tunnel test rig can not cover all the test condition, so we select part conditions to test, then to predict the performance of TAAC by extension method based on the acquired data.

Fig.6 shows the test result of small size sample in staggered arrangement. Fig.6-1 gives 12 rejection result at different hot air flow from 544 kg/hr to 1814kg/hr and temperature difference between the inlet hot air and cooling air from 30, 45 and 60℃. Fig.6-2 gives the pressure drop of cooling air, it can help to select the cooling fan.

From these data, we can predict the performance of the full size TAAC prototype, the prediction result is shown in Fig.7. From it we can see that, 60kW is the rejection requirement at the inlet temperature difference of 105℃ between hot air and cooling air, the max. working ambient is 45℃. In order to meet the rejection requirement at all different condition, we must ensure a certain cooling air flow. Fig.7 also shows that, with the cooling air flow increases, the rejection growth has slowed down.

Because of the compact layout inside the generator cabin, two centrifugal fans are applied to ensure the circulations do work. The external layout of the fan motor can avoid the impact from the high temperatures inside the cabin.

4. FULL SIZE TAAC SAMPLE

4.1. CONCEPT DESIGN AND SAMPLE

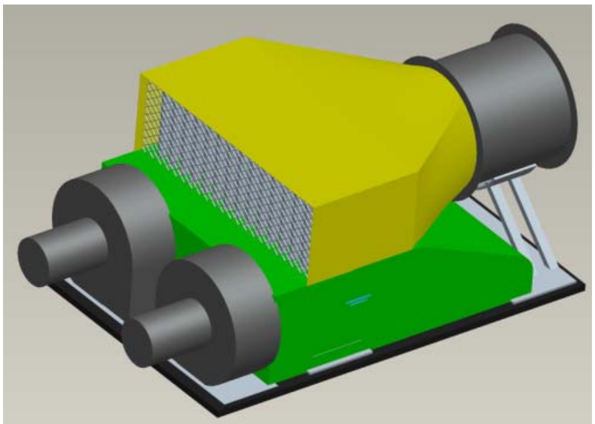


Figure 8 3D concept design of the TAAC

Figure 9 Full size prototype of the TAAC

Based on the test research above, the TAAC should has 60 thermosyphon tubes, the 3D concept design is shown in Fig. 8. Fig. 9 is the final prototype, this prototype shows excellent performance during back to back comparison test with the current cooler .

4.2. CUSTOMER AUTHENTICATION

The length of time from the wind power unit begin to work till the surface temperature of stator and shaft of the generator reaches equilibrium, is a measure of the heat exchanger performance indicators, the less the time used, the better the performance of the cooler will be. From Fig.10 we can see that, it only take the new prototype about 5 hrs to reach the heat balance, it is about 90 minutes less than the current cooler. The blue curve shows that the surface temperature of stator and shaft of the generator is 31.9℃ lower with yinlun prototype compared with the current cooler.

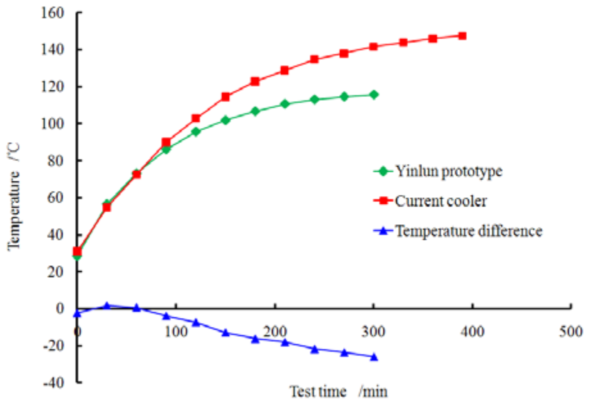


Fig. 10 Customer authentication result

5. CONCLUSIONS

In this paper, a new thermosyphon air-air cooler for wind power generator is developed, there are double flow loop in the hot air side.

Compared with the current cooler, the dimension of the new cooler is 2200×1230×800, it is about 29% smaller in size.

The weight of the new cooler is only 650kg, it is about 13.4% lighter in weight, and it can further to reduce the weight .

The energy consumption is 7kW, 16.3% reduced than the current cooler.

It is about 14.6% improved in cooling capacity than the current cooler.

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