直接空冷系统的实测与设计数据的对比分析

Actual measurement of direct air cooling system and comparative analysis of design data

·东北电力设计院有限公司
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1 概述 Summary

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电厂空冷技术以其优越的节水性能有效的解决了电力发展与水资源相对匮乏的矛盾，成为富煤缺水地区大容量电站的最佳选择。近十年来，越来越多大容量的空冷机组相继投运，尤其是1000MW直接空冷机组投运，成为我国空冷技术发展的里程碑。同时，面对节能减排的严峻形势，国内火力发电机组节能降耗力度的不断加大，节能减排工作已经成为各发电企业的重点工作之一。作为直接空冷发电机组主要辅机系统的直接空冷系统同样面对着提升节能降耗水平的问题。

Air cooling technology of power plant for its superior saving water performance and effective solution to the contradiction between power development and relative lack of water resources, has become the best choice for large capacity power plant between in coal-rich and area of water shortage. In the past ten years, more and more large-capacity air-cooled units have been put into operation, especially 1000MW of operation of direct air cooling unit, which has been a milestone in the development of air-cooling technology in China. Meanwhile, in face of the grim situation of energy saving and emission reduction, the domestic thermal power generating units, energy-saving and consumption reduction will be constantly increased and energy saving and emission reduction have become the one of the main tasks of each generation enterprises. The direct air cooling system, as a main auxiliary systems of direct air cooling electricity generating units, is also facing the issues energy saving and emission reduction.

2 排汽管道阻力
Exhaust pipe resistance

某电厂600MW亚临界机组直接空冷系统，采用双排管空冷凝汽器，从排汽装置至逆流管束出口压降测试结果如下：Direct air cooling system of a 600MW power plant sub-supercritical adopts dual-row air cooled condensers from exhaust equipment to outlet of counter flow bundles ，pressure test results are as follows:

工况 Working condition	单位 Unit	420MW	510MW	600MW	TMCR	TRL
负荷 Load	MW	421.279	517.3	599.7	642.3	600
低压缸排汽流量 **Low pressure cylinder exhaust steam flow**	t/h	885.6	1339.2	1600.9	1303.4	1349
低压缸排汽压力 Low pressure cylinder exhaust steam flow	kPa	19.373	28.442	32.058	13.1	32
排汽装置阻力 exhaust device resistance						
实测排汽装置阻力 Actual measurement exhaust device resistance	kPa	0.121	0.423	0.727	0.586	0.359
计算排汽装置阻力 Calculate the resistance of the exhaust device	kPa	0.072	0.115	0.146	0.225	0.104
实测与计算差值 Actual measurement and calculation difference	kPa	0.049	0.308	0.581	0.364	0.255
实测与计算误差 Actual measurement and calculation error	%	40	73	80	62	71
排汽管道阻力 Exhaust pipe resistance						
实测平均管道阻力 Measured average pipe resistance	kPa	0.254	0.404	0.643	0.785	0.517
计算平均管道阻力 Calculate average pipeline resistance	kPa	0.244	0.392	0.504	0.748	0.347
实测与计算差值 Actual measurement and calculation difference	kPa	0.01	0.012	0.139	0.037	0.17
实测与计算误差 Actual measurement and calculation error	%	4	3	21.6	4.7	33

2 排汽管道阻力
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管束阻力 Tube Bundle resistance						
实测顺流管束阻力 The measured resistance of flow tube bundle	kPa	0.446	0.562	0.74	1.1	0.717
计算顺流管束阻力 Calculation of downstream tube bundle resistance	kPa	0.335	0.543	0.705	1.052	0.812
顺流实测与计算差值 Flow actual measurement and calculation difference	kPa	0.111	0.019	0.035	0.048	-0.095
顺流实测与计算误差 Flow actual measurement and calculation error	%	33	3	5	5	-12
实测逆流管束阻力 The measured resistance of counter flow tube bundle	kPa	0.229	0.385	0.483	0.781	0.543
计算逆流管束阻力 Calculation of counter flow tube bundle resistance	kPa	0.208	0.337	0.439	0.71	0.508
逆流实测与计算差值 Counter Flow actual measurement and calculation difference	kPa	0.021	0.048	0.044	0.071	0.035
逆流实测与计算误差 Counter Flow actual measurement and calculation error	%	10	14	10	10	7

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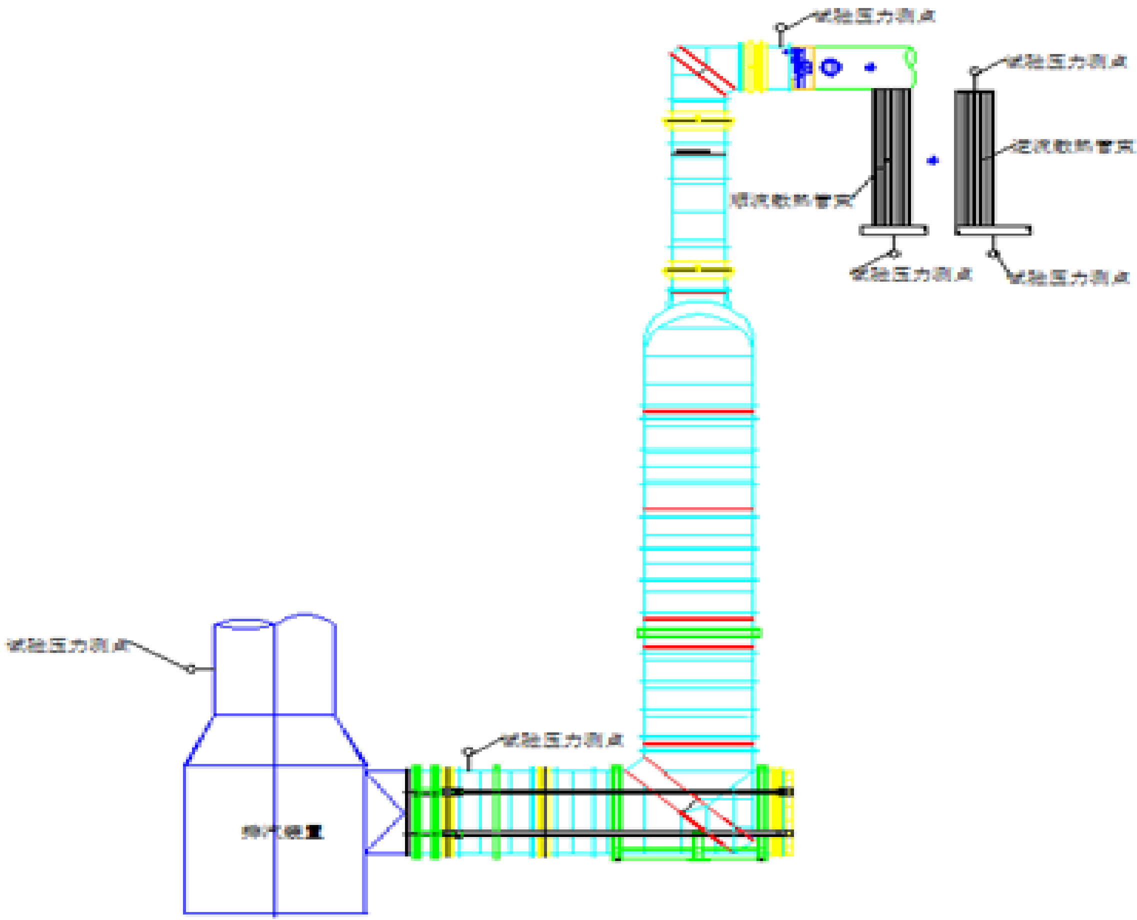

试验压力测点 Test pressure-measuring-point

顺流散热管束 Down flow radiating tube bundle

逆流散热管束 Counter flow radiating tube bundle

排气装置 Exhaust device

2 排汽管道阻力
Exhaust pipe resistance

用实测阻力修正计算TMCR及TRL工况有关参数如下：The parameters of the TMCR and TRL operating conditions are as follows: using the measured resistance correction:

项 目 Project	单位 Unit	TMCR	TRL
原机组设计参数 Original unit design parameters			
设计气温 Design temperature	℃	13	32
设计背压 Design back-pressure	kPa	13.1	32
设计 ITD design ITD	℃	38.19	38.59
设计计算系统总阻力（不含管束） Design calculation system total resistance (Not containing tube bundle)	kPa	0.973	0.451
空冷凝汽器 ITD Air cooled condenser ITD	℃	36.63	38.26
设计计算空冷面积 Design calculation of air cooling area	m^2	1653379	1653379
计算热耗 Calculation of heat consumption	kJ/kWh	8087.07	8583
发电煤耗 The coal consumption for power generation	g/kWh	302.96	321.54
供电煤耗 The power supply coal consumption	g/kWh	330.38	350.64
年耗煤量 Annual consumption of coal	10^4 t/a	107.31	106.11

2 排汽管道阻力
Exhaust pipe resistance

在原设计空冷面积 1653379 m^2 条件下，用实测阻力修正计算 Under the condition of the original design of air cooling area of 1653379 m2, the correction of the measured resistance is used.			
实测修正后系统总阻力（不含管束） Total resistance of the system after the measured modification (not containing tube bundle)	kPa	1.371	0.876
机组背压 Unit back pressure	kPa	13.63	32.56
空冷凝汽器 ITD Air cooled condenser ITD	℃	36.85	38.35
修正后汽机热耗 After Revising turbine heat rate	kJ/kWh	8097.57	8596.76
修正后发电煤耗 After Revising coal equivalent calculation	g/kWh	303.36	322.06
修正后供电煤耗 After Revising power supply coal consumption	g/kWh	330.81	351.21
修正后年耗煤量（标煤） After Revising Annual consumption of coal (standard coal)	10^4 t/a	107.45	106.28

2 排汽管道阻力
Exhaust pipe resistance

在原设计背压 13.1KPa/32 KPa 下，用实测阻力修正计算空冷面积 under the original design of back pressure 13.1KPa/32 KPa, using the measured resistance to amend the calculation of the air cooling area			
实测修正后空冷凝汽器 ITD Measured the amended air cooled condenser ITD	℃	35.96	37.94
实测修正后计算空冷面积 Calculation of the air cooling area after the actual measurement	m^2	1701395	1701395
相对于原设计增加面积 Relative to the original design increase area	m^2	48016	48016

说明：1.厂用电率按 8.3%计算供电煤耗。2.年利用小时数按 5500 小时计算年耗煤量。
3. TMCR 发电功率 643989kw。4. TRL 发电功率 600000kw。

Description：1. Auxiliary Power consumption rate calculated by the 8.3% power supply coal consumption.
2. Annual utilization hour by 5,500 hours calculations year coal consumption. 3.TMCR generated power is 643989kw.4. TRL generated power is 600000kw.

- **按上述数据计算，机组TMCR标准煤耗较设计值上升0.43g/kw.h，TRL标准煤耗较设计值上升0.57g/kw.h，对机组的经济性影响还是相当可观的。如果要保持原设计背压，需增加约两个单元的冷却面积。As stated above data calculating ,standard coal consumption of unit TMCR than design value increase by 0.43g/kw.h, TRL standard coal consumption than design value rose by 0.57g/kW.h， on the unit's economic influence is considerable. If you want to keep the original design back pressure, need to add the cooling area of about two units.**

3 排汽装置阻力
Exhaust device resistance

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Exhaust device resistance

- 近年来，直接空冷汽轮发电机组设计时为了简化汽水系统的设备和管道，减少排汽管道对低压缸排汽口的推力，大多设计了带除氧功能的排汽装置。排汽装置的优点是系统简化，除氧效果好。缺点是排汽装置的阻力较大，汽机厂给出的设计值一般为0.1kPa。 In recent years, the design of the direct air cooling steam turbine generator in order to simplify equipment and pipelines of the steam-water system , reducing exhaust pipes to thrust of low pressure cylinder exhaust steam mouth， most exhaust equipment designed with deoxygenization function. The advantage of the steam exhaust device is simplified system and deoxidizing effect better. Disadvantage is the greater resistance of exhaust equipment, steam turbine plant produces the design value is generally 0.1kPa.

- 由于排汽装置是方形结构，且工作在负压状态，为解决强度及变形问题必须在其内部设置大量的钢管支撑形成立体网格结构，这样就造成其阻力偏大，实际运行时的阻力远远大于制造厂提供的理论设计值，Due to the exhaust unit is a square structure, and in the state of negative pressure the strength and deformation must be set within a large number of forming three-dimensional lattice structure of steel pipe supports, thus causing the resistance is too large, actual resistance far outweigh the theoretical design value of factory provided.

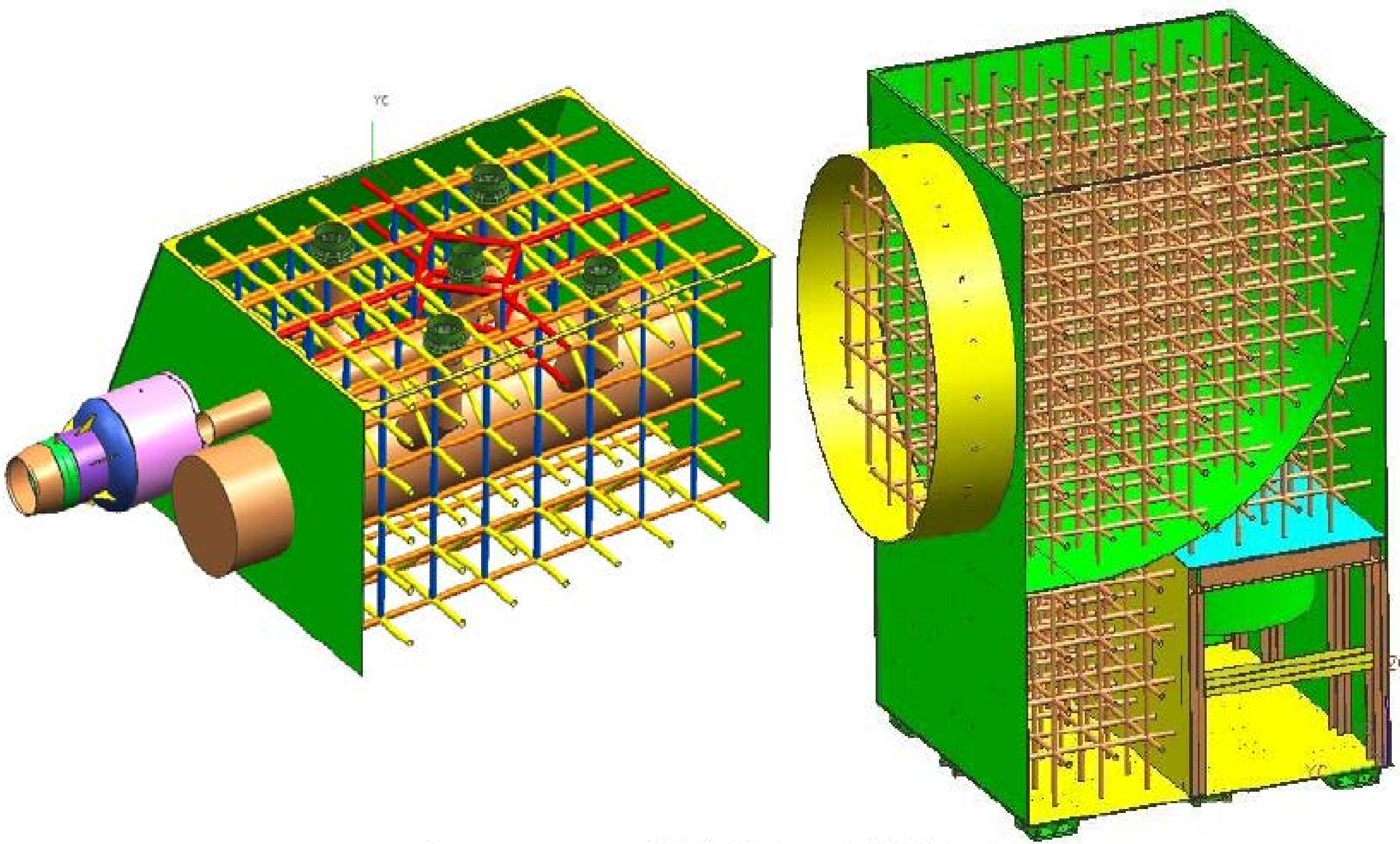

图 3- 1 低压缸排汽管原始结构模型图

3 排汽装置阻力
Exhaust device resistance

项目 Project	单位 Unit	TMCR	TRL
在原设计空冷面积 1653379 m^2 条件下，取消排汽装置，用实测阻力修正计算 Under the condition of the original design of air cooling area of 1653379 m2, cancel the exhaust equipment, calculated by the measured force modified			
取消排汽装置后系统总阻力（不含管束） Total resistance of the system after canceling the exhaust device (not containing tube bundle)		0.785	0.517
取消排汽装置后机组背压 Canceling the back pressure of the unit of exhaust device	kPa	12.83	32.05
取消排汽装置后空冷凝汽器 ITD canceling exhaust device after air cooled condenser ITD	℃	36.49	38.25
取消排汽装置后汽机热耗 Canceling the exhaust device after the turbine heat rate.	kJ/kWh	8081.94	8584.24
取消排汽装置后发电煤耗 Canceling the exhaust device after the coal consumption of power generation	g/kWh	302.77	321.59
取消排汽装置后供电煤耗 Canceling the exhaust device after the power supply coal consumption	g/kWh	330.17	350.69
取消排汽装置后年耗煤量（标煤） Canceling the exhaust device after annual coal consumption (standard coal)	10^4 t/a	107.23	106.12

在原设计背压 13.1KPa/32 KPa 下，取消排汽装置，用实测阻力修正计算空冷面积 under the original design of back pressure 13.1KPa/32 KPa, cancel the exhaust equipment , using the measured resistance to amend the calculation of the air cooling area			
取消排汽装置后空冷凝汽器 ITD Canceling exhaust device after air cooled condenser ITD	℃	36.94	38.21
取消排汽装置后计算空冷面积 Canceling exhaust device after calculating area of air cooling	m²	1630162	1630162

- **通过以上实测结果及分析计算，排汽装置的阻力较大，所以取消排汽装置可以减少空冷换热器面积或降低汽机背压，从而提高空冷岛的经济性。取消排汽装置之后汽水管道系统会复杂一些，但设备及管道的投资不会增加。如果选择适当的真空除氧设备，除氧效果也会有保证的。Through the above actual measurement results and analytical calculation, resistance of exhaust equipment is larger, so the canceling of the exhaust equipment can reduce the area of air cooled heat exchanger or lower turbine back pressure, thereby improving the economy of air cooling island. After removing exhaust equipment， steam and water pipe system will be complex, but investment of equipment and pipeline will not increase. If you select the appropriate vacuum deaeration device, deaeration effect will be guaranteed.**

4 减小过冷度
Reduce supercooling

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Reduce supercooling

- 由于直接空冷机组的排汽通过排汽装置、排汽管道、蒸汽分配管、空冷凝汽器等换热设备，有沿程阻力和局部阻力损失，使凝结水回水温度低于汽轮机排汽压力所对应的饱和温度，这就是直接空冷系统的过冷度。Due to the exhaust unit of direct air cooling through the exhaust steam device, exhaust steam pipes, steam distribution pipe, air-cooled condenser and heat exchanger , along with the loss of on-way and local resistance , the condensate water return water temperature is lower than the corresponding saturation temperature of steam turbine exhaust pressure, which is the degree of supercooling of direct air cooling system.

- **以660MW超临界直接空冷汽轮机为例，主要参数变化见下表：Taking 660MW supercritical direct air cooling steam turbine as an example, the main parameters are changed:**

序 号NO	项 目 Project	内 容 Contents			
1	机组出力（MW） Output of power unit	660	660	660	660
2	过冷度（℃） Degree of supercooling	0	1	3	5
3	1号低加抽汽量（t/h） No 1 extraction flow of low pressure	57.28	59.08	62.77	66.44
4	汽轮机热耗（kJ/kwh） Turbine heat rate	7869	7869	7870	7872
5	设计煤质燃煤量（t/h） Designing coal consuming of coal quality（t/h）	281.3	281.3	281.5	281.7
6	设计煤质燃煤量（t/d）Designing coal consuming of coal quality（t/d）	6752	6752	6757	6760
7	电站总效率（低热值、设计煤） Overall plant efficiency（low heating value、Design coal）	36.65%	36.65%	36.62%	36.60%

- 从上面计算来看，过冷度在1℃左右时，对机组效率基本没有影响，燃煤量也基本没有差别；过冷度在3℃时，机组效率下降0.03%，汽轮机热耗增加1 kj/kwh，日燃煤量增加5吨左右；过冷度在5℃时，机组效率下降0.05%，汽轮机热耗增加3 kj/kwh，日燃煤量增加8吨左右。这对于机组的设计指标和日后的运行来说，还是有一定的影响的。From above calculation , supercooled degrees at about 1 ℃, on unit efficiency basic no effect, coal-fired volume also basically no difference; when degree of supercooling at 3 ℃ , unit efficiency declines 0.03%, turbine hot consumption will increase 1 kJ/kWh and day coal-fired volume increase around 5 tons; supercooled degrees in 5 ℃ , unit efficiency drop of 0.05%, turbine hot consumption increased 3 kJ/kWh, day coal-fired volume increased 8 tons around. It will have a certain influence on the Design indicators and future operation of the unit.

5 利用变频器有效调节风机运行参数
Using the inverter to adjust effectively fan operation parameters

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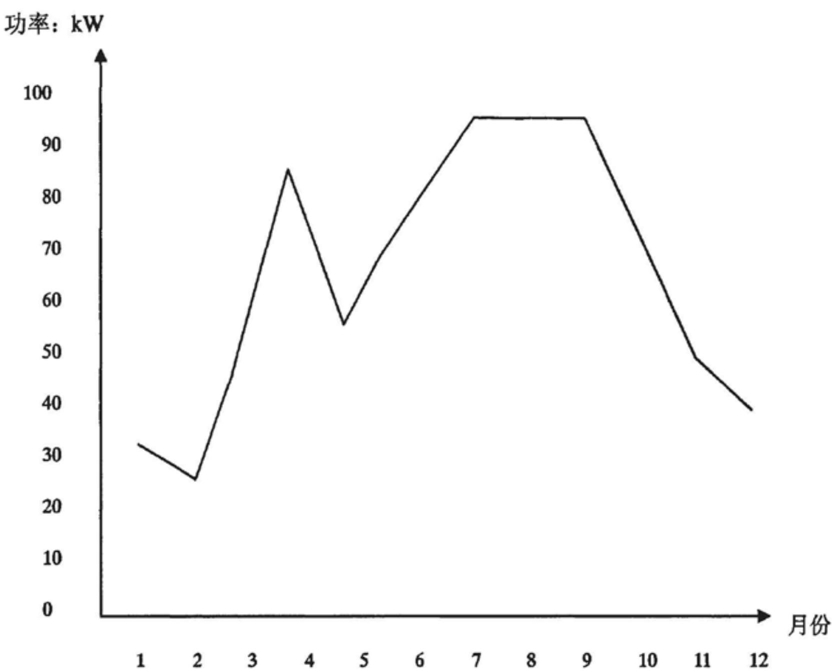
Using the inverter to adjust effectively fan operation

- **风机组是直接空冷系统的主要耗能设备，设计中大多数采用变频调速，在保证汽轮机背压的条件下，根据四季气温的差异，调节风机的转速或者直接减少运行风机台数。降低风机的电耗。The fan units are the major energy-consuming equipment of direct air cooling system， most of using the frequency conversion speed regulation in design, under ensuring back pressure condition of the steam turbine, according to the four seasons difference in temperature, adjusting the fan speed or reducing the number of running wind machines directly. The power consumption of fan should be reduced.**



6 结论
Conclusion

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- 优化排汽管道、蒸汽分配管的布置，合理布置阀门，使汽量分配均匀，减少排汽阻力损失，有利于节能运行。Optimized arrangement of steam pipes and steam distribution pipe and of valves is reasonable, making the steam distribution uniformity, reducing exhaust resistance in favor of energy-saving operation.
- 对于相同的设计条件，单排管空冷器通流面积较大，较双排管和三排管有利于降低蒸汽阻力，凝结水过冷度较小，机组背压相对较低。With regard to the design condition ， single-tube air cooler flow area is larger than double row and third row to reduce the resistance of steam and condensate water supercooling degree is lesser, the turbine back pressure is relatively low.
- 建议新建直接空冷机组取消排汽装置，设置单独的低真空除氧加热器。Proposed new direct air cooling unit to cancel the exhaust device, which will set up separate low vacuum deaerating heater.
- 对于设有排汽装置的直接空冷机组，因各汽轮机厂家的现有排汽装置结构不完全相同，虽然汽轮机排汽与凝结水回水有一定的接触，但接触面积相对较小，对减小凝结水过冷度作用不明显，故应考虑对排汽装置做进一步改进。With regard to direct air cooling unit of the exhaust device, because the existing exhaust device structure of the steam turbine manufacturers is not exactly the same, the turbine exhaust steam and condensate return water have some contact, contact area is relatively small, no obvious effect on reducing supercooling degree of condensate water, exhaust steam device should be considered for making further improvements.
- 变频器调节空冷轴流冷却风机转速、控制起停在节能方面的效益是显而易见的。Frequency converter regulates air cooled axial cooling fan speed ，controlling starts and stops in the energy-saving benefits are obvious.

- 谢谢各位领导和专家！

- THANK!

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