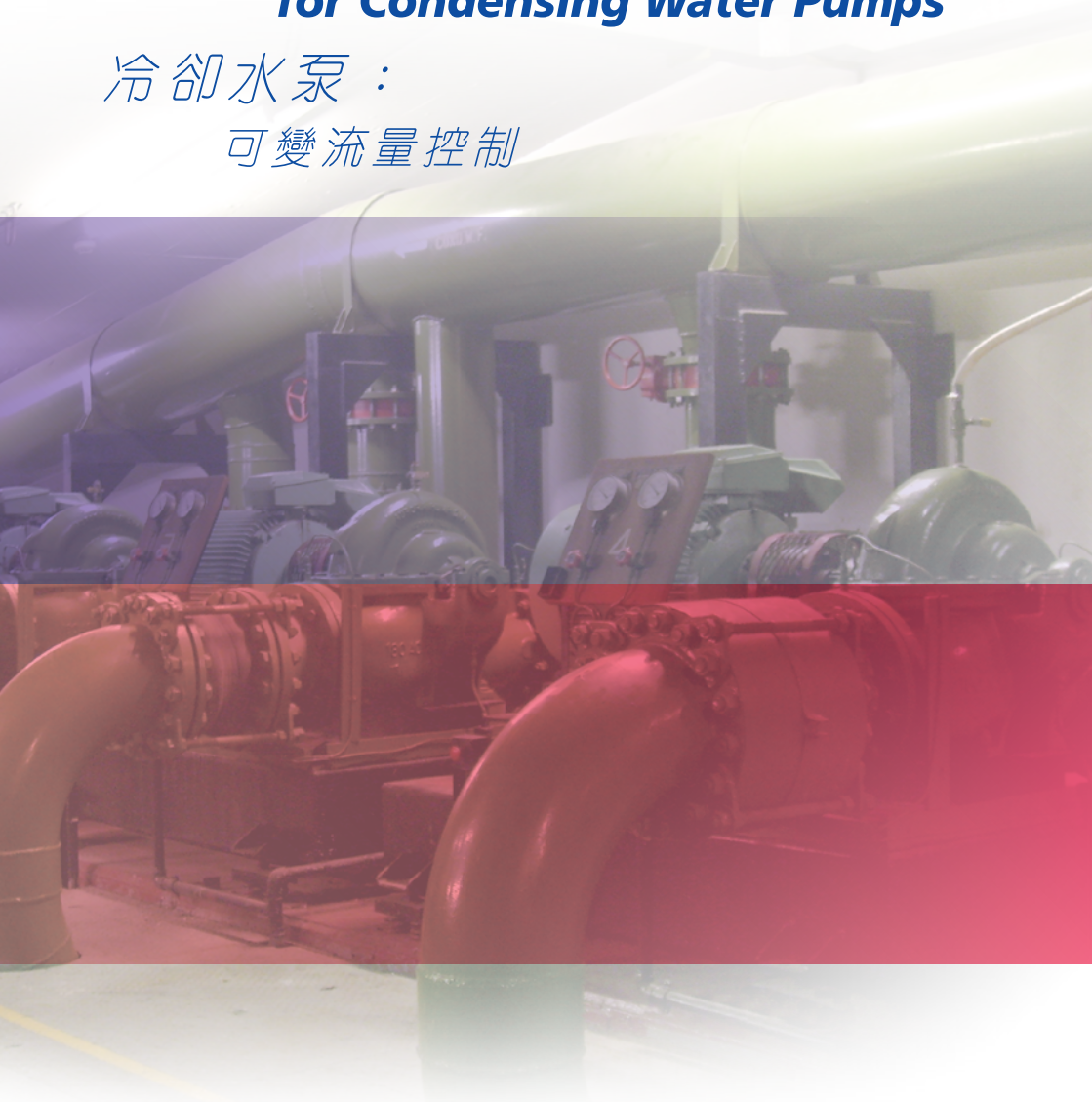


Variable Flow Control **for Condensing Water Pumps**

冷卻水泵：
可變流量控制



Introduction

A water-cooled central air conditioning system usually consists of a refrigeration plant, a chilled water distribution system, a condensing water system, air side equipment and air distribution ductwork. A typical condensing water system for water-cooled central air conditioning system consists of pumps, condenser, a system of condensing water pipework and a heat rejection unit such as cooling tower or heat exchanger etc.

This pamphlet aims to introduce an algorithm for controlling the condensing water pumps for variable water flow operation and discuss its energy saving potential when compared with constant water flow control.

Conventional Control of Condensing Water Pumps

Basically, the heat rejection capacity of a condenser is determined by (1) the temperature difference between the refrigerant and the cooling media through the condenser, (2) the flow rate of the cooling media through the condenser, and (3) the flow rate of the refrigerant through condenser.

引言

水冷式中央空調系統通常包括製冷設備(製冷機)、冷凍水分配系統、冷卻水系統、供風端設備和冷氣風槽。而其中的冷卻水系統則由水泵、冷凝器、冷卻水管道和散熱裝置(如冷卻塔或熱交換器)所組成。

這本小冊子會介紹一種冷卻水泵可變流量的控制方法，並探討其節能潛力。

傳統的冷卻水泵控制方法

基本上，冷凝器的散熱能力取決於(1)製冷劑和冷卻媒體通過冷凝器時的溫差、(2)冷卻媒體通過冷凝器的流量和(3)製冷劑通過冷凝器的流量。

Traditionally, constant flow control is adopted to ensure the system has adequate heat rejection capacity at full load condition. However, as the system often runs at part-load condition, there will be an opportunity to adjust the heat rejection capacity of the condenser downward to suit the actual need of the system and energy saving potential will be derived.

Variable Speed Control for Condensing Water Pumps

Typically, the condensing water pump is connected to the condenser with a system of pipework. Instead of running at constant speed, the speed of the condensing water pump is adjusted by variable speed drive (VSD) according to the temperature of condensing water leaving the chillers. With appropriate setting, the condensing water leaving temperature could be a good indicator for the adequacy of condensing water flow rate.

傳統的冷卻水泵控制多採用固定流量設計，以確保空調系統在滿載時有足夠的散熱能力。然而，由於運作中的空調系統頗多時間都是處於部份負載狀態，對冷凝器的散熱需求會相應減少，向下調整冷凝器的散熱能力以合乎實際負載需要，可達到節能的目的。

冷卻水泵可變流量的控制方法

一般而言，透過冷卻水管道，把冷卻水泵連接到冷凝器。跟據冷卻水離開製冷機的溫度，適當地使用變速驅動器調整冷卻水泵的運行速度，落實冷卻水泵可變流量的控制，便可取代傳統的冷卻水泵固定流量設計。只要設定配合得宜，冷卻水離開製冷機的溫度可以有效地反映冷卻水流量是否足夠。

Principle of Operation

操作原理

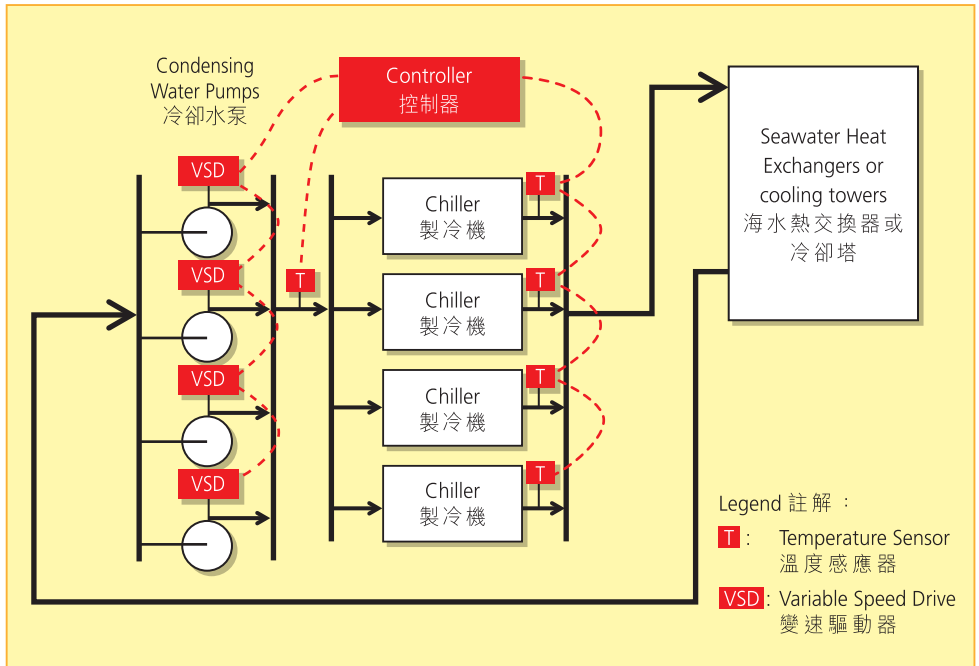


Fig. 1 – Typical Arrangement of Variable Condensing Water Flow System

圖1 - 典型的冷卻水泵可變流量控制系統

The typical arrangement of the control technology is shown in Fig. 1. Basically, the system will control the speed of the condensing water pump in accordance with the condensing water leaving temperature. The typical control algorithm is depicted in Fig. 2.

圖1展示典型的冷卻水泵可變流量控制系統安排。基本上，系統會跟據冷卻水離開製冷機的溫度來調節冷卻水泵的運行速度，圖2展示相關冷卻水泵控制方法的典型流程。

Legend 註解

T_{warning}	<p>Beyond this temperature setting, the variable flow control system will be bypassed. In the determination of this value, the high temperature cutout setting of the chillers must be taken into consideration together with adequate safety margin.</p> <p>當冷卻水離開製冷機的溫度高於這溫度設定值時，系統會繞過可變流量控制裝置。在決定此設定值時，須考慮相關製冷機的冷卻水溫度上限和適當的安全系數。</p>
T_{DBH}	<p>The temperature setting for this upper dead band limit is based on the design condenser entering water temperature and the design condensing water leaving temperature, with adequate margin to allow the pump to speed up before the condensing water leaving temperature reaches the upper design limit.</p> <p>在決定此設定值時，須考慮相關冷凝器進水及出水的設計溫度，並預留適當的安全系數，容許冷卻水泵增加運行速度，避免冷卻水離開製冷機的溫度到達上限。</p>
T_{DBL}	<p>This parameter for the lower dead band limit could be set at around one degree Celsius lower than the T_{DBH} value.</p> <p>此參數為控制區下限值，一般是低於 T_{DBH} 值約攝氏1度。</p>
T_{max}	<p>To allow the system to respond to dramatic increase in condensing water leaving temperature in a faster manner, this is set between the T_{DBH} and T_{warning}.</p> <p>此參數在於使系統能夠比較快地應付冷卻水溫度的急劇提升，一般設定值於 T_{DBH} 和 T_{warning} 之間。</p>

The Energy Saving Mechanism

The control algorithm saves energy mainly by the reduction of condensing water flow during part load conditions by saving condensing water pump power running at a lower speed.

With the decreasing cooling load demand, the potential to reduce the condensing water flow will occur as less heat rejection capacity for the condenser is required. For example, if the condensing water flow could be reduced by 10% to meet the decreasing cooling load demand, the amount of pump energy saving can be estimated as follows according to the Pump Affinity Law:

節能原理

此節能技術的原理主要是減低冷卻水在系統部分負載時的流量，從而把冷卻水泵運行速度減慢，以節省電力的消耗。

隨著空調系統負載的下降，對系統散熱能力的要求也相應減低，降低冷卻水流量的空間便會出現。例如，如果系統負載減少容許我們把冷卻水流量減少百分之十，按照泵浦定律，冷卻水泵的電力需求估計可減低如下：

$$Q_n = Q_o \times (1 - 10\%) \Rightarrow P_n = P_o \times (1 - 10\%)^3$$

$$P_n = 0.729 P_o$$

i.e. The estimated saving of condensing water pump power will be around 27%.
即冷卻水泵的電力需求可減低約 27 % 。

where Q is the volumetric flow rate and

P is the shaft power

Subscript "o" and "n" refer to original and new respectively

註釋 Q：水流量

P：軸功率

下標“o”和“n”分別是代表“原來的”和“新的”

Implementing Control Strategy

The system can be implemented with minor retrofit work if the condensing water pumps are already operating with VSDs. It could also be incorporated into a new system quite easily. The followings are the general prerequisites for implementation of the control system:

- The cooling capacity of the chiller plant should be sufficient (or have spare capacity) for the premises. Undersized plant or marginal plant will have less (or minimal) chance to operate under part load condition which is one of the operating criteria to achieve pump energy saving.
- If the original system is not equipped with VSDs, consideration should be taken for technical requirement of installing VSDs for the pumps.
- Large size condensing pump set and/or long operation hour system provides more opportunities for energy saving with such a control system.
- The minimum pump head requirement of a particular system should be considered, which may limit the lowest possible condensing water flow.

實施控制策略

若冷卻水泵已裝有變速驅動器，我們只要為系統進行小型改裝工程，便可以落實可變流量的控制方案了，把該方案設置於全新的系統亦相當簡單。以下是考慮設置可變流量的控制方案時要注意的一些先決條件：

- 樓宇的製冷機組應該有充足的冷凍容量（或具備一些剩餘容量）。容量不足或僅僅足夠的機組很少有（或沒有）機會在部分負載下運行冷卻水泵，節能空間也相對減少。
- 如果原系統沒有裝備變速驅動器，須同時考慮為水泵安裝變速驅動器的技術要求。
- 較大型的冷卻水泵及 / 或較長的系統運作時間可以提供較可觀的節能空間。
- 應考慮個別系統對冷卻水泵揚程的要求，因這也可能限制了冷卻水的最低流量。

- The design condensing water entering temperature of the chillers and the water flow limit of the chiller condenser may limit the extent of the VSD speed reduction.

Besides, particular attention should be drawn to the chiller penalty as a result of lowering in condensing water flow, which may undermine the energy saving potential of the technology. The chiller penalty herein refers to additional compressor power consumption of the chillers from increased refrigerant pressure lift as a result of insufficient heat rejection at the water-cooled condenser arising from reduced condensing water flow.

Energy Saving from Better Control Strategy

The Variable Condensing Water Flow Control Strategy enables the condensing water pumps to be operated more closely with the cooling demand of the building and reduces energy wastage of excessive condensing water flow. It should however be noted that the achievable energy saving is site specific which depends on the load pattern and the conditions of the plant equipment. For further information, please contact the Energy Efficiency Office of The Electrical and Mechanical Services Department.

- 冷卻水進入製冷機組的設計溫度和冷卻水通過冷凝器的設計最低流量，都會限制了變速驅動器的工作範圍。

此外，應特別注意製冷機組可能因冷卻水流量降低而引致的懲罰函數，這可能影響整體的節能表現。製冷機組懲罰函數是指因為冷卻水流量降低而導致冷凝器散熱能力不足，製冷劑壓力提升，而導致相關製冷機組運作時需要使用額外的電量。

利用更好的控制方法節能

冷卻水可變流量控制策略使冷卻水泵更緊密地依從大廈的冷凍需求運作，減少因過多的冷卻水流量所導致的能源浪費。然而須留意節能效果於不同冷凍水系統是不同的，這取決於大廈的負載模式和製冷系統的狀況。如希望獲得更多資料，請與機電工程署能源效益事務處聯絡。

Case Study

A Variable Condensing Water Flow Control System was implemented in one of the government premises as a pilot project.

個案研究

在一個政府樓宇內安裝了冷卻水可變流量控制系統作為試驗計劃。

Basic Information

Number of condensing water pump:	4 Nos.
Rating of pump motor:	75 kW
Original control system:	Constant Flow
Variable speed drive equipped:	Yes
Pump operating hour:	According to office hours of the building (10 hour per day)
Condensing water circuit:	Centralized Piped Supply System for Condenser Cooling using sea water

個案的基本資料

冷卻水泵數量：	4台
冷卻水泵功率：	75千瓦
原有控制系統：	固定流量
已裝置變速驅動器：	是
冷卻水泵運行時間：	依照大廈的辦公時間（每天10小時）
冷卻水管道系統：	中央管道式冷卻水系統（海水冷卻的冷凝器）

Result of the Pilot Project:

The energy consumption of the condensing water pumps controlled by this technology were recorded from May 2008 to April 2009, which covered a full spectrum of operating conditions from cold winter to hot summer. The monthly energy saving of the condensing water pumps was found to be ranged from 21.4% to 54.5%, with an average of about 33%. In general, the saving is more significant during winter period. The chiller power consumption pattern was analyzed and chiller penalty due to variable condensing water flow was found insignificant in the pilot project.

試驗計劃的結果：

加裝冷卻水可變流量控制系統後，記錄了冷卻水泵從2008年5月到2009年4月的能源消耗。期間包括寒冷的冬天及炎熱的夏天，是一個頗全面的操作環境。在這個試驗個案中該控制系統帶來了每月平均約33%的節能率，範圍由21.4%至54.5%不等，在冬天的節能率比較顯著。與此同時，跟據試驗個案中對製冷機組的記錄分析，製冷機組懲罰函數對該試驗計劃的結果影響輕微。





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