Chiller faults diagnosis: a case study

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Chiller faults diagnosis: a case study

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Abstract. Failure detection and diagnosis (FDD) is one of the condition-based maintenance methods. Implementing chiller FDD one could identify the failure and locate where the failure occurs. With the ability to detect and locate the failure, proper maintenance action could be taken to remedy the situation. In most cases, it could restore the performance and extend the useful life of an asset. One of the well-known FDD methods is a Simple Thermodynamic Model (STM). In this paper, a chiller in a commercial building in Jakarta is subjected to the implementation of STM model. The chiller was monitored before and after maintenance. The necessary operating parameters were recorded and processed then they were used to identify two parameters of the STM model by regressing the STM equation. Based on the result, the faults could be detected and located during four different measurements time; on the second month, the eight-month, the eleventh month, and twelfth month. The results show that the STM model is able to detect the faults and locate where the faults have occurred.

1. Introduction

Chiller is an essential equipment for most commercial buildings. It is used for conditioning the indoor air so that occupant can live and work comfortably. Chiller is also one of the types of equipment that consume high electrical energy. Because of the importance of the chiller, the failure of the chiller can disturb the occupant's comfort. Less comfort means less productivity [1]. In addition, chiller faults or deterioration may also increase energy consumption [2]. Therefore it is important to keep the chiller operating and functioning properly.

There are several types of maintenance such as reactive maintenance, preventive maintenance, and predictive maintenance. The reactive maintenance is performed after the equipment failure. On the other hand, the preventive maintenance is performed before the equipment failure. The last type is predictive maintenance. It is used to predict when maintenance should be performed based on asset or equipment condition. The examples of the predictive maintenance are condition monitoring, inspection, and condition-based maintenance. Maintenance is not only intended to preserve the equipment function but also to prevent the consequence of its failure. Therefore understanding the failure consequences is essential in the maintenance analysis.

A Fault detection and diagnosis (FDD) is an essential tool for chiller condition monitoring. The FDD is used to detect failures earlier and then diagnose the causes of the failure. Knowing the reasons for the failure could help engineers to determine what proper maintenance actions should be done to restore the condition of the asset before additional damage to the system or loss of service occurs [3].

There are several types of FDD methods. They are quantitative model-based, qualitative mode-based, and process history-based. Detail discussion of each method and its derivative can be found in ref [3]. The FDD method we used in this research was a simple thermodynamic model (STM) also known as Gordon-Ng (GN) Universal chiller model [4]. The STM model is a process history-based method and goes into category gray-box method. Gray-box model uses the first principle or engineering knowledge and translates them into a mathematical model, but the parameter utilized in the model comes from process history data [3].

The subject of the study is a vapor compression chiller in a commercial building in Jakarta, Indonesia. The building management has replaced the chiller with a larger capacity but a refurbished one. The reason for the replacement is because the old chiller could no longer meet the current cooling demand. The refurbished chiller was subject to chiller FDD to make sure the chiller operates and functions properly. The centrifugal chiller under study is 400 Ton in the cooling capacity. The chiller operating data was measured and recorded at four different times; after the first operation, during chiller operation, before and after the first maintenance. The simple thermodynamic model (STM) used these recorded data to detect and diagnose the chiller faults.

2. Chiller Measurement

To perform simple thermodynamic model as chiller FDD, one needs to obtain chiller operating data such as inlet and outlet temperature at both condenser and evaporator (water side), water flow rate in condenser and evaporator, and compressor load [R] as shown in Figure.1. The temperature was measured by the built-in thermocouples. The ultrasonic flow meter is used to measure the water flow rate in the condenser. The measurement of evaporator water flow rate is not possible, alternatively, the evaporator flow rate is calculated through energy balance. A good reference for calculating the unknown water flow rate in a chiller system can be found in reference [7] [8]. When the evaporator water flow rate information is available, the cooling load can be calculated. Finally, the chiller coefficient of performance (COP) could be calculated for each point of measurement based on cooling and compressor load.

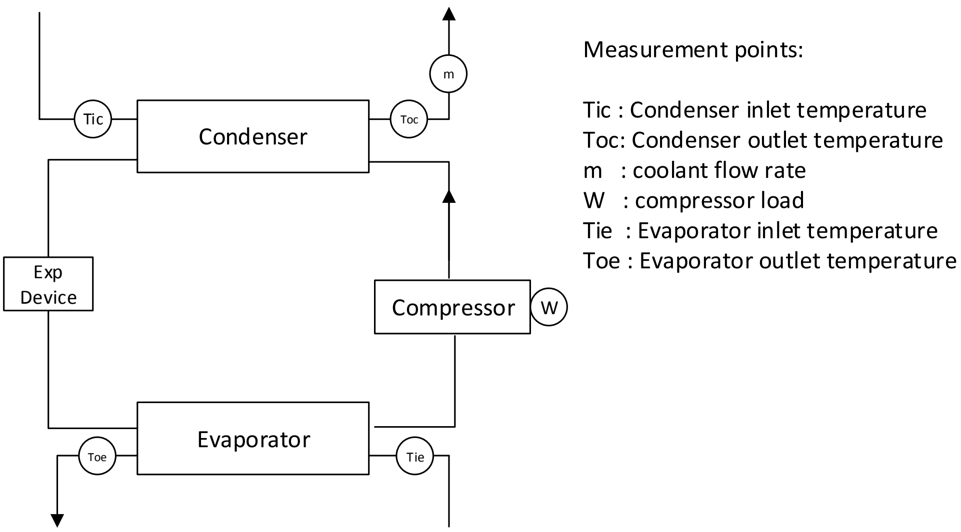

Figure 1. Measurement location schematic

The measurements were performed four times. The first measurement was performed one month after chiller in operation, the second measurement was on the eighth month, the third measurement was on the eleventh month, and the last measurement was performed after chiller maintenance on the twelfth month (Figure.2). The data was recorded to the data acquisition system (DAS) for further analysis except for the condenser and evaporator water flow rate. Condenser and evaporator water flow rate was manually input.

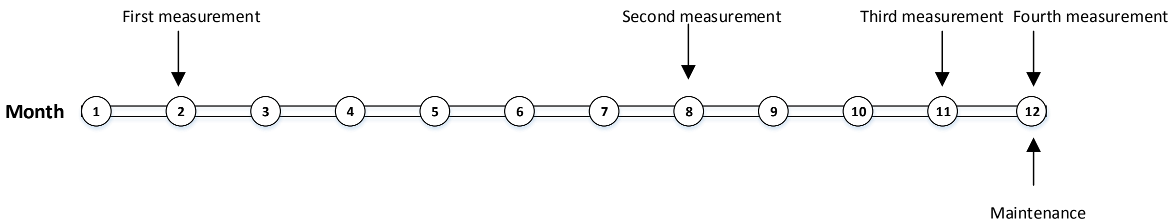

Figure 2. Measurement timeline

3. A Simple Thermodynamics Model (STM)

The simple thermodynamic model (STM), also known as Gordon-Ng (GN) Universal chiller model, is developed from energy and entropy balance [6]. This chiller model predicts three sources of irreversibility in the term of internal dissipation (internal entropy production), heat exchanger thermal resistance, and equivalent heat leak. It is believed that these three sources of irreversibility contribute to the chiller COP. The internal dissipation obtained from a simple thermodynamic model is the total value of entropy generation produced by the systems. The comprises entropy production from evaporator, condenser, compressor and expansion valve. The heat exchanger thermal resistance is a combined thermal resistance for both evaporator and condenser. The thermal resistance represents the finite-rate heat exchange and also be known as external heat loss. The heat leak term is a heat gain/loss from or to the environment. Normally, the value of heat leaks is small [5] and having a small effect on Chiller COP [6]. Therefore it has a small contribution to the application of FDD [5]. However, for an accurate chiller modeling, it is important to incorporate the heat leak term on the equation (2).

The advantage of the universal chiller model application is that it just needs non-intrusive measurement. The measurements are taken on the water side of the condenser and evaporator, and compressor power.

The simplified formula for Gordon-NG chiller model (Simple thermodynamics model) is expressed as the following [2]:

$$\frac{T_{ie}}{T_{ic}}\left(1+\frac{1}{COP}\right)-1=T_{ie}\frac{\Delta S_{int}}{Q_{evap}}+\frac{Q_{leak}\left(T_{ic}-T_{ie}\right)}{T_{ic}Q_{evap}}+\frac{RQ_{evap}}{T_{ic}}\left(1+\frac{1}{COP}\right) \qquad (1)$$

Where:

T_{ie} = Evaporator inlet temperature (K)
T_{ic} = Condenser inlet temperature (K)
COP = Coefficient of performance
Q_{evap} = Cooling load (Kw)
ΔS_{int} = Internal entropy generation (Kw/K)
Q_{leak} = Equivalent Heat leak (Kw)
R = Thermal resistance (K/Kw)

To find the three irreversibility parameters, one just needs to regress the equation (1). The value of internal entropy generation and thermal resistance must be positive. But the value of equivalent heat leak could be negative or positive. Detail discussion about this formula can refer to reference [5].

Because the heat leak term (Q_{leak}) is less dominant than internal entropy generations and thermal resistance, some minor modification has been made to the STM model to enhance its FDD capabilities [5]. The heat leak term is held constant throughout the analysis. Due to constant heat leak term, equation (1) can be rewritten as the following [4] [5]:

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$$\frac{T_{ie}}{T_{ic}}\left(1+\frac{1}{COP}\right)-1-\frac{Q_{leak}\left(T_{ic}-T_{ie}\right)}{T_{ic}Q_{evap}}=T_{ie}\frac{\Delta S_{int}}{Q_{evap}}+\frac{RQ_{evap}}{T_{ic}}\left(1+\frac{1}{COP}\right) \quad (2)$$

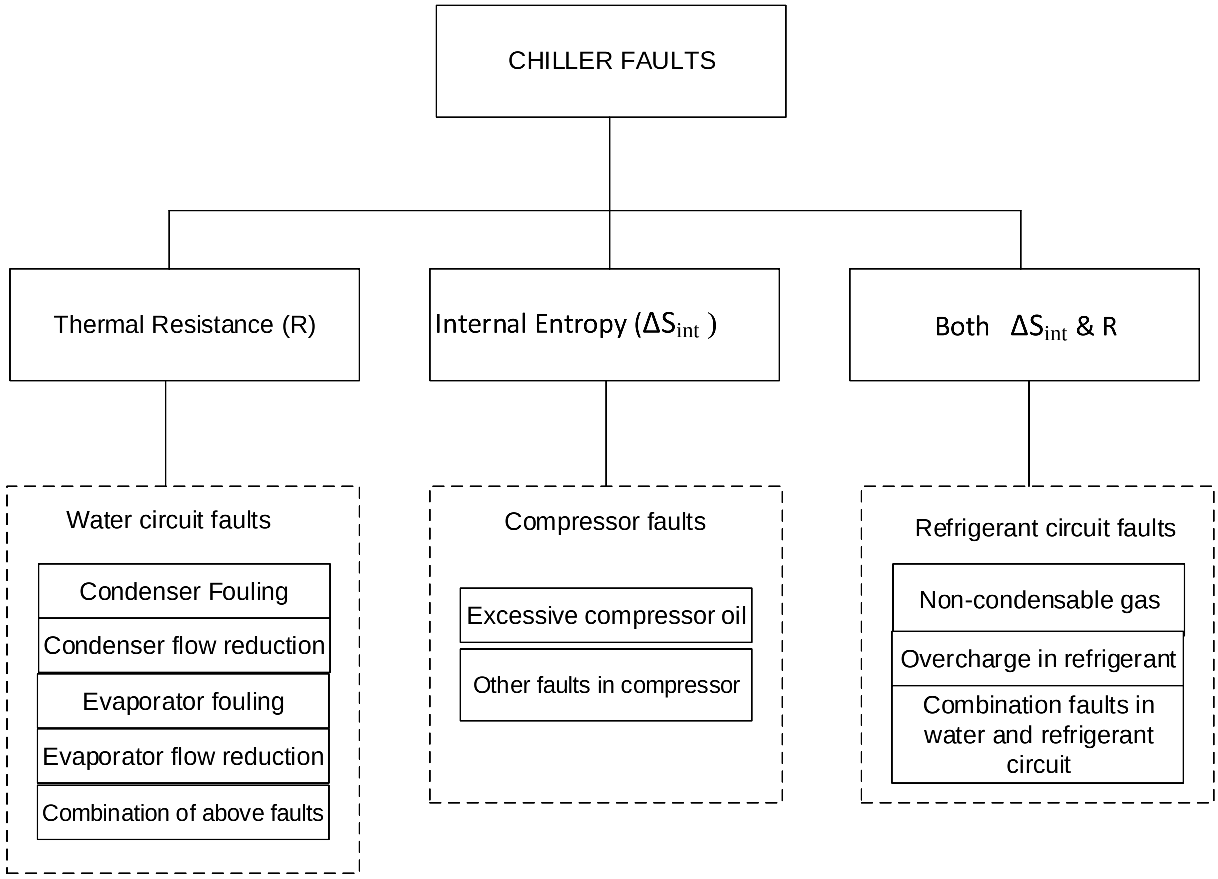

Figure 3. Diagnostic chart for STM method [5]

To interpret the result from the regressed STM parameters, one needs a diagnostic chart (Figure.3) to identify the type of faults. The faults can be classified into three different types [5]. First is faults related water circuit. Next is faults related to the compressor. The last one is faults related to the refrigerant circuit. The diagnostic chart in Figure.2 is slightly modified from reference [5].

4. Result and Discussion

The First-month measurement is the free-fault period and considered to be the baseline. Any deviation in the next several measurements is compared with the baseline. The STM parameters for the first measurement is tabulated in Table 1. The threshold limit is used to identify if faults occur. It is regulated using mean standard error with 68% confidence level and the result is tabulated in Table 2. Any deviation in internal entropy generation (ΔS_{int}) and thermal resistance (R) indicate that a fault has occurred.

The second measurement was performed six months after the first measurement (on 8th month). The STM parameter is tabulated in Table 1. The ΔS_{int} seems to remain constant since the deviation is within the threshold limit (±0.6%). It means that there might be no fault in the compressor. On the other hand,

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the thermal resistance parameter (R) has increased by 41.6% compared to the baseline value. The Deviation in R-value indicates faults in the water circuit since it exceeds the threshold limit (Table.2). The possible faults for deviation in R-value could be further identified from Figure.3. The root mean square error (RMSE) for the first measurement is less than 5% (Table.1), the RMSE less than 5% is considered accurate [4].

Table 1. STM parameters

No	Parameter	2nd month	8th month	11th month	12th month
1	ΔS_{int} (kW/K)	0.607	0.608	0.606	0.607
2	R (K/kW)	0.0021	0.0030	0.0060	0.0020
3	RMSE	0.35%	0.92%	0.38%	1.61%

The third measurement was performed three months after the second measurement. The ΔS_{int} value is still within the threshold limit, therefore, no fault related to an increase in ΔS_{int} happen. However, the R-value is doubled compared to the previous value (The 8th month). The R-value is 183.6% higher than the baseline value. It means that the faults related to the water circuit become more severe. Based on the deviation in R-value, one can prepare a maintenance action that related to water circuit faults with the help of a diagnostic chart (Figure.3) and chiller field inspection.

Faults related to thermal resistance are such as condenser and evaporator fouling, condenser and evaporator water flow rate reduction and a combination of these faults (Figure.3). During chiller maintenance, all possible causes for the four type of faults are investigated. The result indicates that the primary cause for deviation in thermal resistance is condenser fouling. Therefore, condenser cleaning should be performed to restore the heat exchanger performance.

Table 2.Threshold limit

No	Parameter	Average	Limit
1	ΔS_{int} (kW/K)	0.607	± 0.6%
2	R (K/kW)	0.0021	± 15.8%

After condenser cleaning, the chiller measurement was performed again. The result of STM parameters shows that ΔS_{in}t remains constant since its deviation is within the threshold limit (Table.2 and Table.3). It means that no faults related to compressor system happen. After condenser cleaning, the thermal resistance value (R) has restored to the normal value (Table.1 and Table.3). It means that condenser cleaning is able to resolve the fault. Based on the obtained result, one can conclude that the application of STM model for FDD could identify the fouling as well as the severity level of fouling in the heat exchanger during long-term operation. By knowing the possible location of a fault, any necessary action can be prepared to tackle the issue in the next maintenance. In addition, the STM model is also able to identify that the fouling issue has been resolved after the condenser cleaning.

Table 3. Deviation of STM parameters

No	Parameter	8th month	11th month	12th month
1	ΔS_{int} (kW/K)	0.2%	-0.2%	-0.1%
2	R (K/kW)	41.6%	183.6%	-4.1%

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5. Conclusion

Simple thermodynamics model (STM) has been applied to a chiller in a commercial building. The application of STM model for chiller FDD only requires few measurement points at the inlet and outlet of condenser and evaporator (water circuit), compressor load, and water flow rate in the condenser or evaporator. The measurement instruments for those points are usually available in a chiller system, except maybe for the water flow rate measurement. But a portable ultrasonic flow meter can substitute the installation of a permanent flow meter.

The STM method has been applied to four different measurement time. The result from the first measurement is considered to be the baseline. Any deviation in the STM parameter should be compared with the baseline values. The only fault identified during the case study is fouling in the condenser. The STM method is not only able to identify the increase in thermal resistance value but also its severity level. With the help of the diagnostic chart in Figure 3, the possible cause of the faults can be narrowed to water circuit faults. Therefore, the water circuit should be inspected for further investigation. The result of the inspection indicates that the possible cause of the fault is fouling in the condenser. After condenser cleaning, the improvement in the thermal resistance parameter can also be identified with the STM method. In summary, the application of STM method for chiller FDD is easy in the term of what parameter needs to be measured and difficulty level of its analysis.

References

[1] Kosonen R and Tan F 2004 *Assessment of productivity loss in air-conditioned buildings using PMV index* . *Energy and Buildings*. **36** p 987–993

[2] Firdaus N, Prasetyo BT and Luciana T 2016 *Chiller: performance deterioration and performance. Energy Engineering*, **113** p 55-80

[3] Katipamula S and Brambley MR 2005 *Review Article: Methods for Fault Detection,Diagnostics, and Prognostics for Building Systems—A Review, Part I* Journal *HVAC&R Research* **11** p 3-25

[4] Saththasivam J, Tang G and NG KC 2010 *Evaluation of the simple thermodynamic model (Gordon and Ng universal chiller model) as a fault detection and diagnosis tool for on-site centrifugal chiller* . *International Journal of Air-Conditioning and Refrigeration*. **18** p 55-60

[5] Saththasivam J, Tang G and NG KC 2008 *Predictive and Diagnostic Methods for Centrifugal Chiller* . *ASHRAE Trans.* **144** p 282-287

[6] Sreedharan P and Haves P 2001 *Comparison of Chiller Models for Use in Model-Based Fault Detection. Proceeding of first international conference for enhance building operation*.

[7] Zhao X, Yang M and Li H 2012 *Development, evaluation, and validation of a robust virtual sensing method for determining water flow rate in chillers. HVAC&R Research*, **18** p 874-889

[8] Kim W and Braun JE 2012 *Evaluation of Virtual Refrigerant Mass Flow* Sensors. *International Refrigeration and Air Conditioning Conference at Purdue* . 1245