Root Cause Analysis of Cleanroom Relative Humidity Fluctuation and Out of Specification Levels by Applying Cause-Effect Chain Analysis Plus (CECA+)

by

Sri Rahayu binti Salehan
(1832422797)

A dissertation submitted in fulfillment of the requirements for the degree of Master of Science in Manufacturing System Engineering

School of Manufacturing Engineering
UNIVERSITI MALAYSIA PERLIS

2020

ACKNOWLEDGMENT

In the name of Allah, the Most Beneficent and Most Merciful. Thank you for all the strength given in completing this dissertation.

I would like to express my gratitude to my supervisor, Dr. Rosmaini Ahmad for all the guidance and advice during this project period.

Thank you to all party that support this dissertation work directly and indirectly. An appreciation to my family members especially to my husband for all the encouragement and support.

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LIST OF ABBREVIATIONS

ABC	Air Circuit Breaker
AHU	Air Handling Unit
BOM	Bill of Material
C&E	Cause & Effect
CE	Cause & Effect
CECA	Cause Effect Chain Analysis
CECA+	Cause Effect Chain Analysis Plus
CI	Continuous Improvement
CRT	Current Reality Tree
CTQ	Critical to Quality
DRJ	Drilling Router Jig
FCU	Fan Coil Unit
FMEA	Failure Mode Effect Analysis
FRCD	Free Return and Charging Device
FTA	Fault Tree Analysis
FTD	Fault Tree Diagram
HVAC	Heating Ventilating Air Condition
IC	Integrated Circuit
IWB	Innovation Work Bench
LSL	Lower Specification Limit
MAU	Make-up Air Unit
MLB	Multilayer Boards
OEE	Overall Equipment Effectiveness
PC	Personal Computer
PPM	Part per Million
PTH	Plated Through Hole
RAC	Return Air Chamber
RCA	Root Cause Analysis
RCA+	Root Conflict Analysis
RH	Relative Humidity
RPN	Risk Priority Number
SIPOC	Supplier, Input, Process, Output, Customer
SMED	Single-Minute Exchange of Die

SOP	Standard Operating Procedure
SWAN	Set-up 5-Whys Analysis
SPC	Statistical Process Control
TPS	Toyota Production System
USL	Upper Specification Limit
VOC	Volatile Organic Compound/Voice of Customer
VSM	Value Stream Mapping

LIST OF SYMBOLS

P_{IN}	Process Air In
P_{OUT}	Process Air Out

Analisis Punca Masalah Ketidakstabilan dan Tahap di Luar Spesifikasi Kelembapan Relatif Cleanroom Menggunakan Analisis Berantai Punca dan Kesan Plus (Cause-Effect Chain Analysis Plus - CECA+)

ABSTRAK

Dalam industri semikonduktor yang berkaitan, cleanroom adalah sebuah kawasan di mana proses pengeluaran yang sensitif dijalankan. Salah satu proses pengeluaran yang dijalankan di dalam cleanroom adalah proses ujian produk tertentu yang memerlukan persekitaran terkawal termasuk suhu dan kelembapan. Operasi cleanroom tersebut dengan suhu dan kelembapan di luar spesifikasi akan menyebabkan risiko kecacatan produk secara langsung. Projek penyelidikan ini membentangkan aplikasi kaedah Analisis Berantai Punca dan Kesan Plus (Cause-Effect Chain Analysis Plus (CECA+)) bagi menganalisa masalah kelembapan relatif sebuah cleanroom yang berlaku di sebuah industri semikonduktor. Pemantauan tahap kelembapan di salah sebuah cleanroom di syarikat kajian kes menunjukkan corak data yang tidak normal. Memandangkan aplikasi kaedah CECA+ bagi menyelesaikan kajian kes industri berkaitan adalah sangat terhad, ia memberikan motivasi untuk diaplikasikan dalam projek penyelidikan ini. Terdapat dua objektif untuk kajian ini. Pertama, menjalankan analisis punca masalah berdasarkan masalah industri yang dinyatakan dengan menggunakan kaedah CECA+. Kedua, melaksanakan penyelesaian yang dicadangkan berdasarkan keputusan proses analisis objektif pertama. Versi asal CECA+ dilaporkan di dalam Lee, Chechurin, & Lenyashin (2018) terdiri daripada tujuh langkah. Dalam projek penyelidikan ini, satu versi CECA+ yang telah ditambahbaik dengan menggabungkan pengkelasan 5M1E (Man (Manusia), Method (Kaedah), Material (Bahan), Measurement (Pengukuran), Machine (Mesin) dan Environment (Persekitaran)) dalam process mengenalpasti rantaian punca masalah serta penambahan dua langkah (pelaksanaan dan pengesahan tahap keberkesananan idea) dibentangkan bagi mengoptimumkan aplikasi dan perlaksanaan kaedah ini. Perlaksanaan tindakan hasil analisis yang dijalankan menunjukkan kejayaan dalam mencapai objektif yang telah digariskan. Kajian ini merumuskan keperluan analisis punca masalah dengan cara yang berstuktur. Aplikasi CECA+ telah berjaya memberikan panduan kepada proses pencarian punca masalah secara sistematik dan seterusnya dalam mencari penyelesaian masalah.

Root Cause Analysis of Cleanroom Relative Humidity Fluctuation and Out of Specification Levels by Applying Cause-Effect Chain Analysis Plus (CECA+)

ABSTRACT

In related semiconductor industry, the cleanroom is the production area where very sensitive production process is carried out. One of the production processes that perform in the cleanroom is the specific product testing under tight environmental control including temperature and humidity. The operation of cleanroom with out of specification directly risks in producing defects product. This research project presents the application of cause-effect chain analysis plus (CECA+) method to systematically analyse the problem of cleanroom relative humidity that occurred at a semiconductor industry. The monitoring data of humidity level at one of the cleanroom in the case study company shows the abnormal pattern. Since the application of CECA+ method to solve industry related case studies is very limited, thus this given a motivation in this presented research project. The objective of this study is twofold. The first objective is to perform root cause analysis based on mentioned industry problem by applying the CECA+ method. The second is to implement the proposed solution that come from the analysis process of the first objective. The original version of CECA+ presented in Lee, Chechurin, & Lenyashin (2018) consists of seven steps. In this research project, an improved version of CECA+ that incorporated 5M1E (Man, Method, Material, Measurement, Machine and Environment) for cause chain classification and other two steps added (implementation idea and verify effectiveness of the idea) are presented to optimize the application and implementation of the method. Implementation of action derived from the analysis showing outlined objective was successfully achieved. This study concludes that the need to carry out the root cause analysis in a structured way. The application of CECA+ that presented in this research project successfully guides the discovery process of the problem in a systematic way, thus leads to identify the feasible solution.

CHAPTER 1 : INTRODUCTION

1.1 Introduction

This chapter presents the introductory information of the research project under consideration. The first section of this chapter is the background of the research project describing information on the nature of the manufacturing area under study. Overviews of the case study which discussing subject under study and the main related systems are discussed in the second section. The third section of this chapter describes details of the problem statement followed by the project objective and scope in the fourth and fifth sections, respectively. The last section of this chapter outlines the dissertation layout.

1.2 Background of Research Project

Based on definition by ISO14644-1, a cleanroom is an enclosed space or room with airborne particles controlled which constructed to minimize introduction, generation and retention of particles in the area with other relevant parameters such as temperature, humidity and pressure are controlled as necessary. In manufacturing industry, cleanroom build to have a controlled manufacturing environment to protect product manufactured from harmful airborne contamination. As example, for integrated circuits and hard drives manufacturing, cleanrooms are built to have the product manufactured in controlled airborne particles environment which is harmful to the product while in biotechnology and medical lines, cleanrooms are built to protect the product from bacteria, viruses and other pathogens (Bhatia, 2015).

In electronic and semiconductor industry, manufacturing process in cleanroom are widely implemented with temperature and humidity directly and strictly controlled to full fill specific product or process requirement. Failure in achieving the temperature and humidity within the specification will potentially cause product failure in meeting specific product requirement or process failure which could involve equipment failure and interference in process parameter stability.

This research project basically focuses on conducting a systematic root cause analysis to investigate the relative humidity fluctuation problem in a cleanroom which required to be controlled under tight relative humidity range to full fill a product testing requirement. The success of this research in meeting the objectives will help in improving the cleanroom air conditioning system performance stability and minimizing uncertainties of the system operation.

1.3 Case Study Overview

The case study of this research project was conducted in a manufacturing company which classified under semiconductor/electronic type of industry. The main products of the company are wafer carriers and shippers for semiconductor wafer and filtration products for process gases and fluids and ambient environment. Worldwide, the company also produces liquid systems and components, high-performance materials and specialty gas management solutions, specialized graphite, silicon carbide and coatings. Align with more stringent customer product cleanliness requirement, the company also continue exploring opportunities to have cleaner manufacturing environment with more consistent performance. Cleanroom environment control is one of the areas given special attention ensuring the process and product produced achieving the desired quality.

1.3.1 Relative Humidity and Cleanroom HVAC System

Cleanroom with stringent Relative Humidity (RH) control is required for specific purpose such as to prevent defect on moisture sensitive material and to secure product testing equipment operation. Relative Humidity or saturation level is the amount of water contained by a pound of air at a specific temperature and atmospheric pressure. When air has 50% relative humidity (RH), it is 50% saturated. The air contains about half the water it could hold at the same temperature and pressure. As air approaches 100% saturation, it can take on less and less water until at 100% RH, the air is no longer capable to hold more water (Bry-Air, 2010).

Basically, moisture in a manufacturing cleanroom can come from following sources which will be part of area to be analysed in this case study:

1. Population load – moisture generated by people work in cleanroom.
2. Product load – moisture brought in by product manufactured.
3. Process load – moisture generated from manufacturing processes.

Typically, cleanroom heating, ventilating and air-conditioning (HVAC) system consisted of Make-up Air Unit (MAU) and Air Handling Unit (AHU) to serve one or more cleanroom as shown in Figure 1.1. MAU typically designed to supply required amount of treated fresh outdoor air needed to be conditioned before mixed with re-circulated for cleanroom (Tsao et al., 2010). MAU consists of filters, a centrifugal fan and cooling coil. Meanwhile, AHU works in conditioning the supply air consists of filters, cooling coil, heater, axial fan and humidifier (Zhuang, Wang, & Tang, 2019). Unlike conventional air condition system for thermal comfort and allow humidity fluctuation, adding humidity as a control objective will makes, the system control become more complex as cooling and dehumidification system required to be coupled (Tang, Wang, & Shan, 2018; Homod, 2014; Zhang et al., 2012).

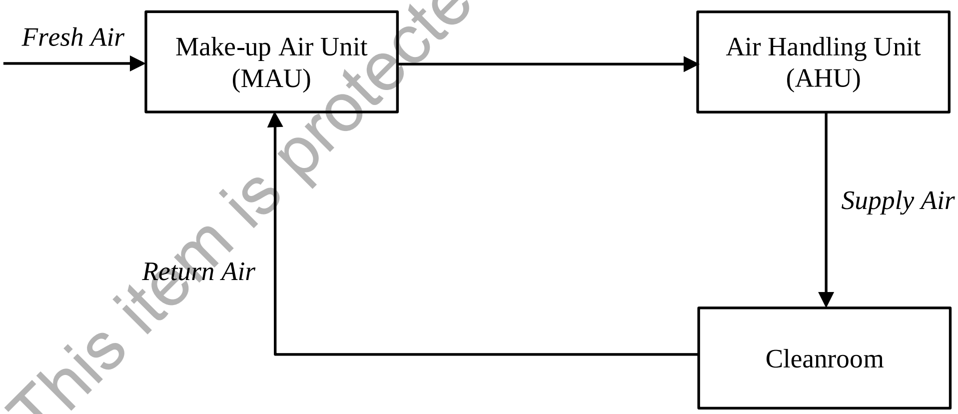

Figure 1.1: Typical cleanroom HVAC system

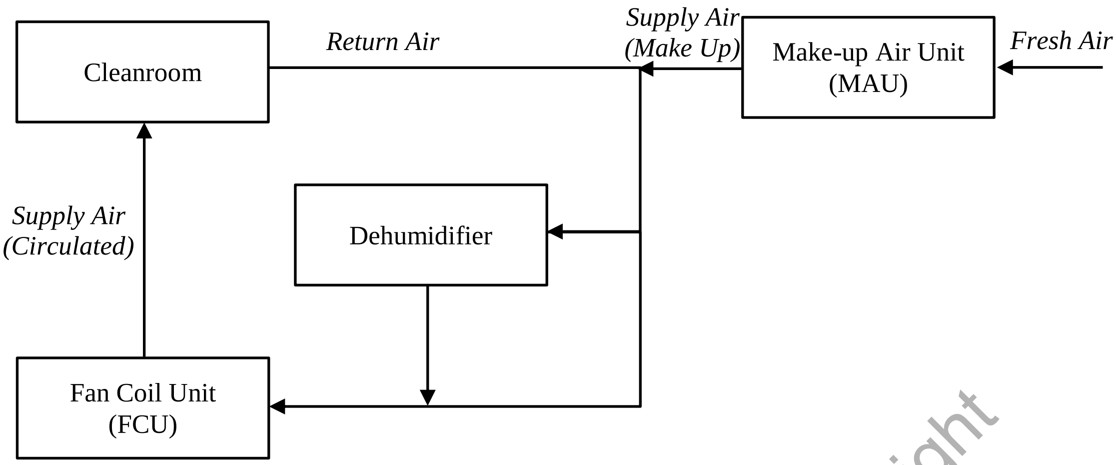

Figure 1.2: HVAC system for cleanroom of the case study

For some cases, like the cleanroom in this case study which require very stringent RH control range designed with added dehumidifier and fan coil unit (FCU) (as shown in Figure 1.2) within the cleanroom air circulation between the cleanroom and return air chamber to maintain the temperature and RH. Meanwhile, outdoor treated air supply set at low flow rate to compensate air lost within the cleanroom circulation system.

1.3.2 Dehumidification System

Dehumidification is the key process for RH control system. Air dehumidification typically can be achieved through few methods such as air compression, reducing air temperature and applying desiccant (Bry-Air, 2010). In this case study, the air dehumidification system under consideration is desiccant based dehumidifier.

In desiccant based dehumidifier, process air enters through the process air inlet and moves through the desiccant media. The desiccant then adsorbs the water vapour and the dehumidified air is then delivered through the process outlet directly into the controlled space or air stream. Then, as the desiccant media rotates into the reactivation air stream, the hot air entering through the reactivation inlet drives off the moisture and exhausts it into the atmosphere. After reactivation the hot, dry desiccant rotates back into the process air stream where a small portion of the process air cools the desiccant so that it can begin the adsorption process all over again. Typical desiccant based dehumidifier system is shown in Figure 1.3.

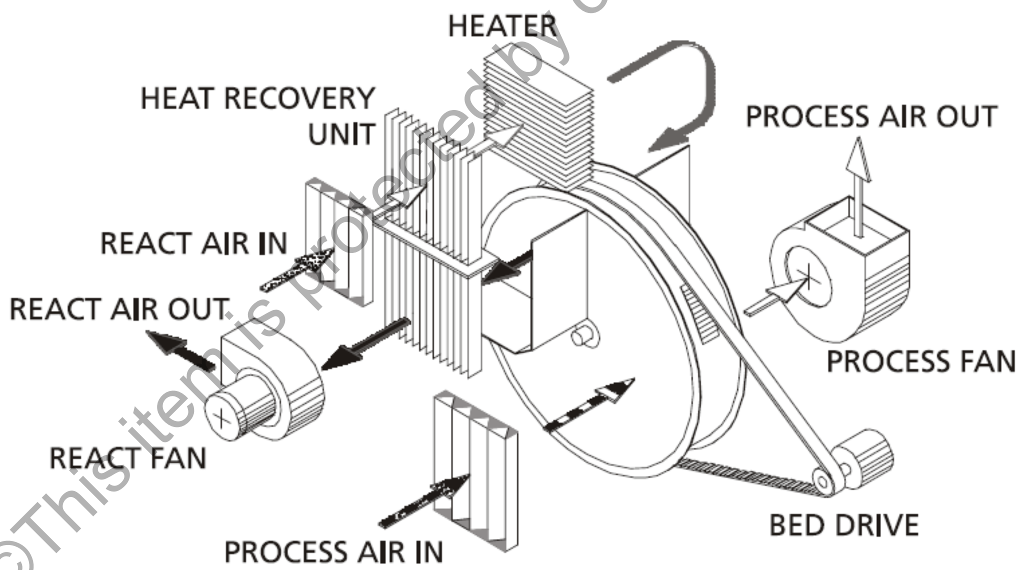

Figure 1.3: Typical Desiccant Based Dehumidifier System (Bry-Air, 2010)

Learning that relative humidity that influenced by moisture load into HVAC system and performance of the humidifier unit, therefore these two areas (HVAC system and humidifier unit) will be one of subject for study in this research project.

1.4 Problem Statement

In a wafer and reticle handling products manufacturing facility, an ISO 5 cleanroom built to locate a Volatile Organic Compound (VOC) tester for wafer and reticle handling products. As the design of HVAC system of this cleanroom presented in Figure 1.2, the VOC tester required to be operated in relative humidity range of 30-50% to secure the tester and ensure measurement accuracy. However, the cleanroom relative humidity monitoring data (as shown in Figure 1.4) showing cases of out of upper specification limit (USL) with huge fluctuation. The five days data of relative humidity performance of the VOC tester cleanroom captured did not show any specific pattern makes the root cause analysis become more challenging. These data pattern directly putting the tester in risk towards system failure and inaccuracy of measurement data produced. This issue also led to uncertainty of product quality supplied to customer and putting the company into risk of customer dissatisfaction.

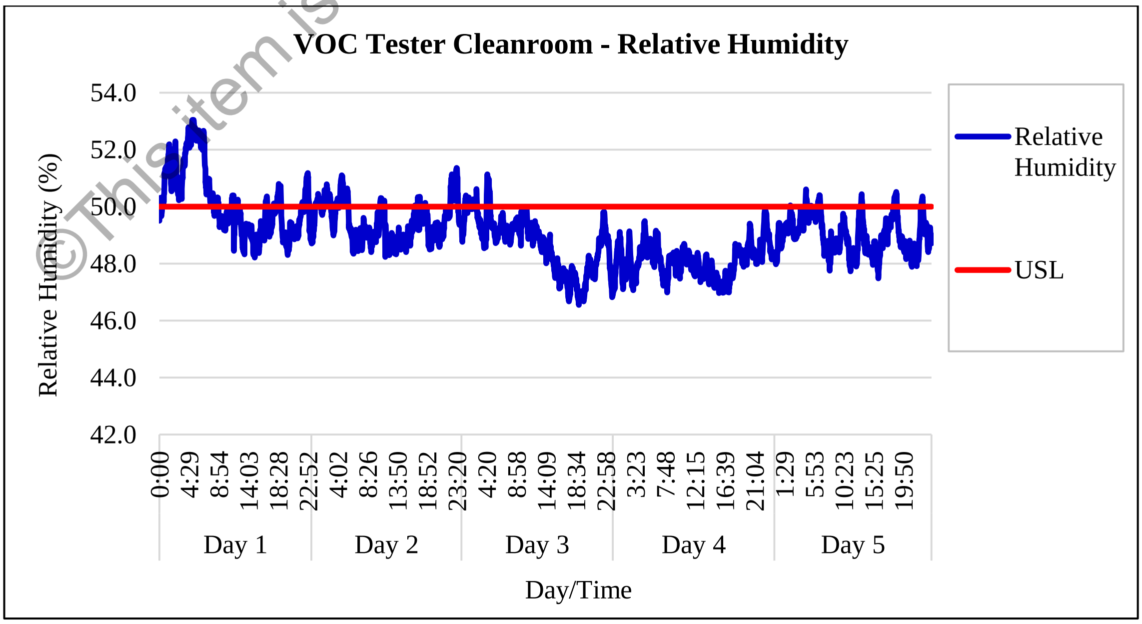

Figure 1.4: Relative Humidity in VOC Tester Cleanroom

Therefore, it is an important need to solve this problem by using structured methodology to really understand the problem and the root cause(s) of the problem from different perspectives. Therefore, the problem under study is systematically explored, analysed and evaluated, hence the right solution strategies can be proposed and implemented.

1.5 Objective

The objectives of this research are:

1. To analyse the problem of relative humidity fluctuation and out of specification levels in a cleanroom by using Cause-Effect Chain Analysis Plus (CECA+) method.
2. To recommend feasible solution that can improve the cleanroom relative humidity fluctuation and out of specification problem based on the results of CECA+ application.

1.6 Scope

1. The research is limited to the VOC tester cleanroom under study and related operating system only.
2. The reliability of data collection will be based on current data collection equipment provided by the case study company.

1.7 Dissertation Layout

This section is outlining the overview of this dissertation project. Chapter two of this dissertation provides a literature review related to root cause analysis methods discussing both traditional and modern techniques inclusive of the advantages and disadvantages. The discussion also covers the development of the CECA+ method which applied for this project. In Chapter two, application of different root cause analysis method in industries are reviewed together with successful stories of encouraging results achieved. Chapter three will be describing the methodology of the dissertation project. The step by step of the CECA+ method application for this project will be described in this chapter. Subsequently, the root cause analysis result and the discussion presented in Chapter four which also covering the lesson learned from the root cause analysis exercise. In Chapter five which is the final chapter presents the conclusion of the overall project findings covering result interpretation of the study, the significance, implication and limitation of the findings. This chapter also relates the findings to the project objectives whether they are successfully achieved.

CHAPTER 2 : LITERATURE REVIEW

2.1 Introduction

This chapter presents the literature review study on related subject under study. The first section introduces the root cause analysis (RCA) followed by discussion on the RCA techniques which divided into traditional and modern method in the subsequent section. A review of RCA applications in industries and the successful achievements are presented in the third section. Finally, the last section of this chapter summarizes the overall literature review findings.

2.2 Root Cause Analysis (RCA)

Root Cause Analysis (RCA) is a collective term that describes wide range of approaches, tools, and techniques serves as cause identification of problems (Andersen & Fagerhaug, 2006). The application of RCA suits various fields with different purposes. Generally, RCA can be defined as a process of analysis to define problem, understanding the causal mechanism from desirable to undesirable condition and identifying root cause of a problem to prevent recurrence by applying structured procedure (Okes, 2005).

In manufacturing industries, RCA widely used in day to day problem solving related to manufacturing operation. RCA helps in solving issues in many aspects such