Analysis of the Defects of Condenser from the Brazing Furnace: A Case Study of an Automotive Condenser Manufacturer

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Abstract

In a case study condenser manufacturer, the automotive condenser was assembled in a brazing furnace where most of aluminium components were brazed together to form the fin and tube heat exchanger. In the Fiscal year 2012 (FY2012), many defected condensers caused by the brazing furnace were about 10% of total condenser products. Previously, only few literatures have reported the reduction of defects caused by the brazing furnace. A paper focused on the defect reduction by data mining approach applied to the model-A condenser. To solve defect problems, the defective check sheet was preliminary developed to record and identify the major defects; types, frequency, locations, and their root causes. The defects normally occurred at the heat application points. The solution to these condenser defects could be carried out by the enhancement of heat distribution among the condenser components. Improvement of the configuration of supporting tools could reduce the major defects and increase production yield. Therefore, the top 10 defects decreased from 9.39% in FY2012 to 6.14% in the first quarter of FY2013. The authors hope that the information shared by this article could enhance defect reduction caused by brazing furnaces in the other related industries.

Keywords: Brazing Furnace, Manufacturing Process, Automotive Condenser, Defect Analysis.

I. INTRODUCTION

Automotive industries have been currently expanded worldwide. Increasing demand of automobile enlarged the requirement of automotive parts supplement. The automotive condenser, a basic component, was constantly installed in every automobile. Therefore, the automotive condenser manufacturers were spread around the world.

In the condenser production line, the aluminium was highly consumed, and normally assembled to form the condenser in the brazing furnace. To indicate the production effectiveness and utilization of the natural resource, it was necessary to index the energy consumption and the production yield.

To achieve the highest production yield, minimizing defects in the assembly process should be carried out. From the literature review, many researches have been done to analyse and reduce the defect, for example, implementing a novel defect detection method by Root-cause Machine Identifier (RMI) with 3 action phases that consists of data pre-processing, candidate generation and measurement. The method was associated with rule mining techniques [1]. Koksal et al. [2] reviewed articles about quality improvement by data mining applications from 1997 to 2007. The problem solving software has been developed to collect, analyse, and quantify the product quality [2].

Fig. 1 Abnormal position clustering dispersion diagram by Kun-Lin Hsieh, [5]

Data mining approach was an initial stage in defect analysis. Some researchers used data mining approach as their starting point in quality control [1, 2, and 5]. Data analysis by data mining techniques...
would clarify various multiple key parameters for quality improvement. The yield loss model for manufacturing process was probable analysed by data mining techniques using artificial neural networks (ANNs) and stepwise regression techniques [5]; i.e., defect status clustering effect as depicted in Fig. 1, showing the diagram of abnormal position defect as clustering effect in TFT-LCD (Thin-Film Transistor-Liquid Crystal Displays).

Moreover, the process factors could be optimized to pull-down defects by Design of Experiment approach with Signal-to-noise estimation, robust design factor analysis by ANOVA and validated using Fisher’s test [6]. The deployed defects per million opportunities (DPMO) would define defect opportunity of the mechanical and electrical industries [7]. The revised control chart by applied fuzzy theory with engineering experience was used in monitoring the defect considering the defect clustering [8]. The implemented Toyota Production System (TPS) concept could improve the work efficiency by reducing non-value added work with low-cost automation or Karakuri Kaizen [9].

According to above literatures, various techniques were used to control and analyse the defect found in industrial processes. However, the research on those mentioned techniques in the automotive condenser, especially data mining, has not been found. For that reason, this work applied data mining approach to record type, quantity and position of defect from the condenser assembly process. The research aims to analyse the root cause and to minimize the defect, specifically at brazing furnace, the key process. The data mining concept is applied to develop the Defective Check Sheet as shown in Fig. 5, 6 and 9 defining the frequency of defective area as defect mapping. The target was to improve productivity and to save cost of condenser assembly lines. Afterward, the natural resource; aluminium and energy, could be utilized effectively.

II. STATEMENT OF PROBLEM

In Thailand, the automotive condenser manufacturer started operation for long-term operated to support the automobile industries. The largest manufacturer was selected as the case study in this research. Nevertheless, the assembly lines were recently recovered and started up after the flooding crisis in Thailand during the end of year 2011.

During the period 2011-2013, the manufacturer has faced a problem of a lot of defects found at condenser that assembled from the Brazing furnace. The high defective rate affected productivity, profit, and opportunity to deliver high quality products to customers. Therefore, the defect data was recorded systematically since June 2012.

In FY2012 (April 2012 – March 2013), average defective rate was totally about 12%. Unfortunately, the defect reached 20% in some months. Then, many measures have been implemented to solve the problem, for example, adjusting temperature of brazing furnace from zone 1 to zone 6 individually, adjusting brazing furnace mesh belt speed, and varying space between condensers while loading to brazing furnace, etc.

Consequently, the defective Pareto chart was developed for the Model-A condenser based on defect data during June 2012 to March 2013 as shown in Fig. 3, accumulating defect frequency, sorting by number (largest to smallest) except the last item (Others) which combined all negligible defects.

Total defect quantity during 10 months period was 19,731 pieces (100%), which over 50% of total defects were contributed by the top 3 defect types consisting of (1) tube scratched, (2) unsoldered bracket, and (3) unsoldered fins. As a result, the research focused on top 3 defects of a model-A condenser, almost found at brazing furnace process.

III. METHODOLOGY

The defect Pareto chart was developed for the Model-A condenser based on defect data during June 2012 to March 2013 as shown in Fig. 3, accumulating defect frequency, sorting by number (largest to smallest) except the last item (Others) which combined all negligible defects.

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Fig. 2 Schematic diagram of a case study, model-A condenser [10]

Fig. 2 illustrates all condenser components of the case study, model-A condenser [10]. The flow direction of refrigerant are shown with position of louvered fin, flat tube, distributor, upper bracket, lower bracket, inlet pad, outlet pad, receiver dryer and pressure switch. The refrigerant flows through the inlet pad and distributor, and then two-phase flows into flat tube having multi-flow pattern. There are 4 multi-flow passages consisting of 44 flat tubes. Each tube passage contains 17, 12, 9 and 6 tubes, respectively.

Fig. 3 Defective Pareto chart of the model-A condenser during June’2012 - June’2013
The analysis was started from the 4M concept; Man, Machine, Material and Method, to identify the root cause of the relevant defects. The 4M analysis could be summarized as follows:

1) **Man**: Assembly process of the condenser was semi-automatic. The operation control was very important to maintain the standard of high quality production among all operators.

2) **Machine**: All of the relevant tools and jigs of the machine were adjusted to support the critical points of condenser. The TPM (Total Productive Maintenance) was implemented associated with Japan Institute of Plant Maintenance (JIPM). TPM house consists of 8 pillars activities: (1). Focused Improvement (FI), (2). Autonomous Maintenance (AM), (3). Planned Maintenance (PM), (4). Education Training (ET), (5). Early Management (EM), (6). Quality Maintenance (QM), (7). Office Improvement (OI) and (8). Safety/Environment (SE) with all employee participation. Considering for improvement, the Overall Equipment Efficiency (OEE) should reach zero break-down, zero defect and zero accident. For AM, the machine operator should be trained for self-maintenance, and for Preventive Maintenance (PM) based on scheduling maintenance of severe machine. However, the brazing furnace has been usually operated based on the dealer’s manual.

3) **Material**: Every condenser components were supplied by the outsourcers or in-house makers. These parts must follow the engineering specification, including standards on physical (geometry, dimension, configuration) and chemical (material composition) properties.

4) **Method**: Depending on the ISO/TS16949 standard requirements; including procedures, work instructions, check sheet, document control, etc., the work and time study should be implemented with continuous improvement.

The production improvement would reduce the relevant defects during the assembly process in the brazing furnace. The defect analysis would identify the root cause of the problems. The author expected that the defective ratio would reduce to reach the acceptable level at 3%.

### III.Brazing Furnace Condition

The brazing furnace is responsible in brazing all aluminium components of the condenser together to configure the heat exchanger. The Brazing furnace consists of 7 heating zones. The first zone called Dry-Off zone is for pre-heating and eliminating residual moisture. The subsequent 6 zones are relevant in controlling conditions to maintain quality of aluminum melting and soldering. The length of each zone and their temperature setting up were summarized in Table I.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Brazing Furnace Physical Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Zone Length (mm)</td>
</tr>
<tr>
<td>Dry Off</td>
<td>3,000</td>
</tr>
<tr>
<td>Zone 1</td>
<td>2,953</td>
</tr>
<tr>
<td>Zone 2</td>
<td>2,680</td>
</tr>
<tr>
<td>Zone 3</td>
<td>2,081</td>
</tr>
<tr>
<td>Zone 4</td>
<td>2,010</td>
</tr>
<tr>
<td>Zone 5</td>
<td>2,010</td>
</tr>
<tr>
<td>Zone 6</td>
<td>2,283</td>
</tr>
</tbody>
</table>

The brazing furnace needed the input of temperature profile following the recommendation from the machine maker as illustrated in Fig. 4. The recommended maximum temperature at Zone 6 was 615°C, the melting point of aluminium. The linear progression was set for the Zone 1 to Zone 6. The cooling down zone, after Zone 6, recommended minimum cooling rate at -50°C per minute. The ambient condition was controlled by the oxygen concentration, recommending lower than 100 ppm. However, the actual temperatures have been adjusted reasonably to reduce the defect as much as possible.

![Fig. 4 Recommended temperature profile by the Brazing Furnace maker [10]](image)

### IV. Defective Check Sheet Implementation

A measure to reduce the defect was to implementing the “Defective check sheet” for recording and analysing the defect data. The analysed information should be able to answer the following questions;

- How many types of defect?
- How many defects in each type? and
- Where are the locations of those defects?

Fig. 5 illustrates the defect check sheet for routine recording of the model-A condenser. All defect types, quantities and positions have been captured for further analysis.

Fig. 6 shows the frequencies of defects highlighted by colour shades. To identify the root causes, this information was mapped with the condition during process control.
The top 3 defects as referred to the Pareto chart (Fig. 3); tube scratching, bracket not soldered, fins not soldered were categorized by their positions as shown in Fig.7.

Firstly, the “tube scratch” defect was often found at the position 12, 10, 13 and 11, respectively. These points located at the corner of condenser which heat easily over-supplying as compared to the other positions. When tube absorbed large amount of heat at these positions, aluminium on tube surface will be over-melted and flown-off and then generated scratch on the tube.

Secondly, the “Bracket not soldered” defect, was mostly found at position 3, at a corner of the condenser nearby the Outlet Pad (heaviest component), because of heaviest component part absorbed larger heat. Then, the surrounding areas received under-heat supply. Whenever heat was not sufficient, the bracket cannot reach the melting point of aluminium, causing not soldering defect.

Thirdly, the “fin not soldered” defect was regularly found at position 10, 13, 11 and 12, respectively, caused by similar root cause as the second defect. Heat was under-supplying to almost fin because of nearby heavier component parts absorbed such heat.

V. EXPERIMENTAL AND VALIDATION

The defect types and quantities recorded by the defective check sheet (Fig.5) were analysed, especially at the problem areas of condenser (Fig.6). Fig.7 shows contribution of those major defects by their positions. The most often defect was due to unbalanced heat supply. Therefore, an experiment was conducted for measuring temperature profile of relevant components of the Model-A condenser.

The temperature measurement at 3 different locations of condenser is shown in Fig.8. The measurement was done by thermocouple type-K with SUS316 shield. Fig. 8 and 9 shows three measuring channels categorized by part density; channel 1 (high density), channel 2 (low density), and channel 3 (moderate density). The lightest one contained only the flat tubes and louvered fins. The moderate one located at the bottom-right corner. It was noted that the channel 1, 2 and 3 were located at the position 12, 32 and 11, respectively. The measured results from these positions were related to defective check sheet.
VI. RESULTS AND DISCUSSION

The automotive condenser which normally composed of various aluminum parts having difference shape, size, position, density were assembled together prior being fed through the brazing furnace tunnel for heat application by hot air. Heat was supplied from the hot ambient air in the brazing furnace along the tunnel, so that it was possible to achieve good heat diffusion through those condenser components. Temperature at the interfacial of both assembled parts should reach the melting point. In fact, it was difficult to maintain appropriated temperature distribution. Therefore, it would be risk causing defects as aforementioned.

Considering the defective check sheet, the highest defect, tube scratch (Fig.10), was caused by overheating of particular parts found at condenser corner (bottom-left and top-right). The tube scratch was found on the tube between channel 2 and 3, because they were lightest and had high potential to be overheated. The other defect, bracket not soldered (see Fig.11), was found at the point 12. This was because the bracket was a heavy component, so that heat dissipation was slowly as compared to the lighter component. As a result, temperature build up in the bracket was not sufficient to solder the bracket with the other components. It could be concluded that incomplete soldering was because of insufficient heating.

Similarly, the problem encountered by the “fin not soldered” at position 32 (channel 12) was due to insufficient heat supply. Heat diffused slowly to the interface of the attached components so that aluminum could not be completely brazed together.

In this research, the defect locations correlated to the defective check sheet, would be clarified by the heating conditions of the brazing furnace; overheating or insufficient heating.

The solution to these defects should be carried out by the enhancement of heat distribution among the condenser components. The operating condition in the brazing furnace could be improved by rearranging the supporting tools to reduce overheating and insufficient heat supplying. The engineer has much attempt to redesign the existing supporting tools and jigs for better heat dissipation from low to high density components. The improvement should be carefully done by using predictive simulation tools called ANSYS, so that the probable configuration of the tools could be obtained.

After improvement of heat balance among the condenser components, the statistics of top 10 defects is illustrated in Fig. 12. It was obviously shown that the pattern of top defects has been changed. The tube scratch defect dropped to the 5th order. However, the Pareto chart (Fig. 13) for the first quarter of the FY2013 (April – June 2013) after improvement shows that the accumulated “tube scratch” defect was still the highest one. The top 3 defects; tube scratch, bracket not soldered, and fin not soldered, reduced significantly after October 2012 (Fig. 14) and dropped to below 200 pieces in June 2013. The contribution of each major defects from the monthly total defects are shown in Fig. 15, which the fin not solders, bracket not soldered and tube scratch were below 2%.

As a result, contribution of the top 10 defect reduced from 12.12% in FY2012 to 7.84% in FY2013.

Fig. 12 Statistics of top 10 defects of the model-A condenser during June 2012- June 2013.
VII. CONCLUSION

The brazing furnace was one critical machine used in assembling various aluminum components of the fin-louvered, the model-A condenser. The defect problem found in brazing process of the automotive condenser was investigated. Based on literature survey, the data mining approach was applied for defect data analysis. Therefore, starting from June 2012, the defective check sheet was developed and utilized for recording and analyzing of the top 3 defects; tube scratch, bracket not soldered, and fin not soldered. The type, quantity, contribution and position of defects were analyzed to identify their root cause. The influence of insufficient heat distribution among various components of the condenser was remarked. Moreover, an experiment was conducted to measure the temperatures at 3 sensitive positions to verify the defect the analysis result from the defective check sheet. It was found that the actual defect locations were correlated to the defective check sheet. It could be concluded that the major root cause was from unbalanced heating conditions by the brazing furnace environment at the component interface, leading to overheating or insufficient heating.

Improvement of the configuration of supporting tools could reduce the major defects and increase production yield. The defect frequencies, in comparison before and after improvement, were changed considerably. The highest defect, tube scratch, dropped to 5th order. The contribution of top 10 defects decreased from 9.39% in FY2012 to 6.14% in the first quarter of FY2013.

Thereafter, the operating conditions and the supporting tools and jigs of condenser in the brazing furnace must be redesigned for better heat balancing to obtain better temperature distribution on the condenser surface. The authors wish that this defect reduction guideline gained from this research would be beneficial to the related industry. For the future improvement, the theoretical part by prediction the temperature contour on condenser would complement.

The table below summarizes the top 10 defects before and after improvement.

<table>
<thead>
<tr>
<th>Top 10 Defects</th>
<th>FY2012 average(%)</th>
<th>FY2013 average(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TUBE scratch</td>
<td>2.84</td>
<td>0.59</td>
</tr>
<tr>
<td>BRACKET not soldered</td>
<td>1.96</td>
<td>0.72</td>
</tr>
<tr>
<td>FIN not soldered</td>
<td>1.01</td>
<td>1.85</td>
</tr>
<tr>
<td>FIN drop</td>
<td>0.56</td>
<td>0.29</td>
</tr>
<tr>
<td>M-TUBE TAKE OFF</td>
<td>0.49</td>
<td>0.01</td>
</tr>
<tr>
<td>FIN UP</td>
<td>0.43</td>
<td>0.07</td>
</tr>
<tr>
<td>FIN tear</td>
<td>0.47</td>
<td>0.95</td>
</tr>
<tr>
<td>SIDE PLATE drop</td>
<td>0.45</td>
<td>0.05</td>
</tr>
<tr>
<td>TUBE leak</td>
<td>0.44</td>
<td>0.22</td>
</tr>
<tr>
<td>FIN MELT</td>
<td>0.47</td>
<td>0.01</td>
</tr>
<tr>
<td><strong>Total Top 10 Defects</strong></td>
<td><strong>9.39</strong></td>
<td><strong>6.14</strong></td>
</tr>
</tbody>
</table>

Fig. 13 Defective Pareto chart of the model-A condenser during April – June 2013 (after improvement).

Fig. 14 Top 10 defects chart during June 2012 – June 2013.

Fig. 15 Top 3 defects statistics during June 2012 – June 2013.

The top 10 defects contribution in percentage, before and after improvement by aforementioned techniques, as compared between FY2012 and FY2013 (Jan - Dec), is summarized in Table 2. The tube scratch and bracket not soldered defects could be reduced to below 0.8%. In contrary, the fin not soldered defect increased to 1.85%. The strange phenomenon of this fin not soldered defect was its rapidly increasing during Mar-Apr 2013, which would be diagnosed in the next research step (see also Fig. 14).
redesigning of the support tools, based on prioritized defective points.

ACKNOWLEDGMENT
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ABBREVIATION

TPM  = Total Productive Maintenance
FI   = Focused Improvement
AM   = Autonomous Maintenance
PM   = Planned Maintenance (Preventive, Periodic)
ET   = Education Training
EM   = Early Management
QM   = Quality Maintenance
OI   = Office Improvement
SE   = Safety/Environment
OEE  = Overall Equipment Efficiency

REFERENCES