FAILURE MODES AND EFFECTS ANALYSIS OF THE AUTO COOLING FAN MOTOR

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Abstract: According FMEA method, this paper represents the results of the analysis of causes and modes of failure of the cooling fan motors as a part of the cool liquid cooling system of vehicle. Description of the FMEA method is pointed out in the introduction of the paper. Based on detailed review of the structure and operation modes of the observed object and other relevant data, FMEA discovered the weak place in the construction of the fan-motors, and then after necessary reconstructions we repeat investigation which gave positive results. In conclusion, the paper presents possible applications of the achieved results and the effects of the cooling fan motors reconstructions.

Key words: Reliability, FMEA, Cooling fan motor

1. INTRODUCTION

During the last decades customers changed their buying behavior. After World War II the customer demand was very high and unsatisfied. Suppliers were producing only necessary goods and in restricted quantities. During the time transaction between customer and suppliers took place. The transaction from the typical sellers market too the buyers market was the result. Globalization and World Wide Web are keywords for the society nowadays. Due to the fact that time and distance are becoming relative, customers are placing increased demands on high quality and reliable products. Therefore manufacturers invest a lot of time and money to increase quality. But the increasing capabilities and functionality of many products are making it more difficult for manufacturers to maintain the quality and reliability. Traditionally, reliability has been achieved through extensive testing and use of techniques such as probabilistic reliability modeling. These are techniques done in the late stages of development. The challenge is to design in quality and reliability early in the development cycle. Therefore engineers introduced Failure Modes and Effects Analysis (FMEA). FMEA is a methodology for analyzing potential reliability problems early in the development cycle where it is easier to take actions to overcome these issues, thereby enhancing reliability through design. FMEA is used to identify potential failure modes, determine their effect on the operation of the product, and identify actions to mitigate the failures. A crucial step is anticipating what might go wrong with a product. While anticipating every failure mode is not possible, the development team should formulate as extensive a list of potential failure modes as possible. The early and consistent use of FMEA in the design process allows the engineer to design out failures and produce reliable, safe, and customer pleasing products. FMEA does also capture historical information for use in future product improvement.

A subject of research are cooling fan motor type MH-140 KL, products of company Zastava PES Surdulica, implemented for car cooling systems and heating or air conditioning of passenger space in the bus. Production of those electro motors is done according to different technical requests and standards of auto industry. Former request of duration period of electro motors with collectors has been 500 hours of work. Today the most famous world producers of cars and other vehicles demand duration period of 3000 working hours and 10000 hours for buses.

In accordance with producer’s regulation task of research is to increase duration time of electro motors with collector from 500 to 3000 hours. Application of FMEA in re-design process of the auto cooling fan motors MH-140 KL is done, potential hazards and failures are identified and premeasures are defined for problems overcoming and lifetime of systems increase.

2. SIGNIFICANCE AND ROLE OF VEHICLE COOLING SYSTEM

Security and safety have a special place in all vehicles’ types. Safety increase can be achieved by taking measurements of accident prevention (active security) or, taking measurements for minimum consequence in case of accident (passive security). Vehicle cooling system is one of most important system for internal-combustion engine security and safety. It provides that engine’s working temperature is in permit limits and without breakdown.

Fig. 1. Diagram of a cooling system
Components of car cooling system (Fig. 1): liquid, radiator, water pump, thermostat, tubes, fan electro motor (in further text electro motor with working circuit), it need to reduce temperature in very short time and to prevent internal-combustion engine damage.

The most important system for vehicle cooling system is electro motor, it moves rotor of working circuit, and in further course it will consider EM structure and functional way.

3. FMEA & FMECA

Failure Mode and Effects Analysis (FMEA) is a structured, qualitative analysis of a system, subsystem, or function to identify potential system failure modes, their causes, and the effects on the system operation associated with the failure mode’s occurrence. If, as is usually the case, the FMEA is extended to include an evaluation of the failure criticality – as assessment of the severity of the failure effect and its probability of occurrence – the analysis is called a Failure Mode, Effects, and Criticality Analysis (FMECA) and priorities are assigned to the failure mode.

The FMEA task generally demands two sets of requirements. One set, which is called general requirements specifies the implementation requirements, input information requirements, and documentation or output requirements. The implementation requirements provide general information and ground rules such as: how the FMEA will be performed, and to what level of abstraction it will be performed. The input requirements define the information needed from designers, system engineers, reliability and safety engineers. The documentation or output requirements of the FMEA task can take on many different forms depending on the applicable standards. The documentation of the information produced by the FMEA must provide the needed critical information without unnecessary details. The other set of requirements, called detailed requirements, consists of the analytical portion of the FMEA. The FMEA takes a systematic approach for determining and evaluating each system, subsystem, part and component historical failure modes. This aspect of the analysis is called the failure mode portion FMEA. Once the failure modes have been defined for the system, the potential effects, or impact on each part of system are evaluated according to the mission system safety.

The FMEA can be extended to determine the criticality of the effects of each failure mode according to criticality criteria which involve the probability of the failure mode and the severity of the effect. The formal approach to this analysis was developed and documented in US Military Standard 1629. It is used to assess the safety of various system components, and to identify design modifications and corrective actions required to reduce the effects of a failure on the system. Although FMECA is often thought of as a safety analysis, its main benefit is that the system designers learn more about the system while provide the analysis. Hence FMECA should be done iteratively as the design develops.

A FMECA is potentially one of the most beneficial analyses done in a well reliability program. It is also one of the most tedious, time consuming, error prone and difficult in development of a product. Hence a computerized aid needs to be developed to help in performing the analysis.

The FMECA methodology is based on a hierarchical, inductive approach to analysis. Before beginning, the analyst must have a good understanding of the system components and the system operation and mission. The analyst then determines how every possible failure mode of each system components, affects the system operation. When the analysis is completed the analyst should have a clearer and deeper understanding of the system components and their relationships to the system operation and mission.

As mentioned in the previous section FMECA extends the FMEA to include the probability of the item failure modes and prioritize them for corrective actions. Traditionally, the criticality assessment is performed by either
- developing a Risk priority Number (RPN)
- calculating an item criticality number.

The RPN method is used mostly in the automotive industry and the criticality number techniques is used mostly in the nuclear and aerospace industry.

We will pay attention in this paper especially RPN techniques. The RPN criticality assessment uses linguistic terms to rank the probability of the failure-mode occurrence, the severity of its failure effect, and the probability of the failure being detected on a numeric scale from 1 to 10. These ranking are then multiplied to give the RPN. Failure modes having a high RPN are assumed to be more important and given a higher priority than those a lower RPN. The criticality number calculation described in MIL-STD-1629A, first categorized the severity of the failure mode effect and then develops a ‘criticality ranking’ which is, in essence, the probability of a failure with that severity occurring. The procedure consists of determining the failure effect probability (β), the failure mode ratio (α), the part failure rate (λ) and its operating time (t), and using these values compute a criticality number for each item failure mode severity classification.

4. TYPES OF FMEA’S

There are several types of FMEA’s. Some o them are used much more often than others. FMEA’s should always be done whenever failures would mean potential harm or injury to the user of the end item being designed. The different types of FMEA can be seen in table 1.

<table>
<thead>
<tr>
<th>FMEA – types</th>
<th>usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>System</td>
<td>focuses on global system functions</td>
</tr>
<tr>
<td>Design or Construction</td>
<td>focuses on components and subsystems</td>
</tr>
<tr>
<td>Process</td>
<td>focuses on manufacturing and assembly processes</td>
</tr>
<tr>
<td>Service</td>
<td>focuses on service functions</td>
</tr>
<tr>
<td>Software</td>
<td>focuses on software functions</td>
</tr>
</tbody>
</table>
4.1. FMEA usage

When do we use FMEA? In the past, engineers have done a good job of evaluating the functions and the form of products and processes in the design phase. But the designing in reliability and quality was a huge problem. Often the engineer uses safety factors as a way of making sure that the design will work and protected the user against product or process failure. As described in an article from the Mechanical Engineering: “A large safety factor does not necessarily translate into a reliable product. Instead, it often leads to an over designed product with reliability problems.”

With FMEA the engineer get a tool with can assist in providing reliable, safe, and customer pleasing products and processes. FMEA helps the engineer to identify potential product or process failures.

FMEA can be used to develop product or process requirements that minimize the likelihood of those failures. FMEA is also the basis for:

- Evaluate the requirements obtained from the customer or other participants in the design process to ensure that those requirements do not introduce potential failures.
- Identify design characteristics that contribute to failures and design them out of the system or at least minimize the resulting effects.
- Develop methods and procedures to develop and test the product/process to ensure that the failures have been successfully eliminated.
- Track and manage potential risks in the design. Tracking the risks contributes to the development of corporate memory and the success of future products as well.

FMEA ensures that any failures that could occur will not injure or seriously impact the customer of the product or process. There are several different approaches to do a Failure Modes and Effects Analysis. One possible way is described in the following chapter. This way is a combination of two different internet sources. One is from Kenneth Crow and the other from Nomogen. In figure 3-1 we can see an overview about the FMEA procedure. It starts with the FMEA Planning and Team Creation down to FMEA – Development and then to the Evaluation of the results.

4.2. Severity

Severity is an assessment of the seriousness of the effect and refers directly to the potential failure mode being studied. The Customer in process FMEA is both the internal and where appropriate, external Customer. The severity ranking is also an estimate of how difficult it will be for the subsequent operations to be carried out to its specification in Performance, Cost, and Time. The Ranking and suggested criteria are listed in table 2.

A common industry standard scale uses 1 to represent no effect and 10 to indicate very severe with failure affecting system operation and safety without warning. The intent of the ranking is to help the analyst determine whether a failure would be a minor nuisance or a catastrophic occurrence to the customer. This enables the engineer to prioritize the failures and address the real big issues first.

4.2.1. Causes of failure mode

Identify the causes for each failure mode. A failure cause is defined as a design weakness that may result in a failure. The potential causes for each failure mode should be identified and documented. The causes should be listed in technical terms and not in terms of symptoms. Examples of potential causes include improper torque applied, Improper operating conditions, too much solvent, improper alignment, excessive voltage etc.

4.3. Occurrence

The Occurrence is the assessment of the probability that the specific cause of the Failure mode will occur. A numerical weight should be assigned to each cause that indicates how likely that cause is (probability of the cause occurring).

For that failure history is helpful in increasing the truth of the probability. Therefore historical data stored in databases can be used and questions like the following are very helpful to solve this problem.

- What statistical data is available from previous or similar process designs?
- Is the process a repeat of a previous design, or have there been some changes?
- Has the environment in which the process is to operate changeable?
- Have mathematical or engineering studies been used to predict failure?

A common industry standard scale uses 1 to represent unlikely and 10 to indicate inevitable. The Ranking and suggested criteria are can seen in table 3: Occurrence ranking and suggested criteria.

Table 2. Severity guidelines for design FMEA (1-10 qualitative scale)

<table>
<thead>
<tr>
<th>Effect</th>
<th>Rank</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>1</td>
<td>No effect.</td>
</tr>
<tr>
<td>Very slight</td>
<td>2</td>
<td>Customer not annoyed.</td>
</tr>
<tr>
<td>Slight</td>
<td>3</td>
<td>Customer slightly annoyed.</td>
</tr>
<tr>
<td>Minor</td>
<td>4</td>
<td>Customer experiences minor nuisance.</td>
</tr>
<tr>
<td>Moderate</td>
<td>5</td>
<td>Customer experiences some dissatisfaction.</td>
</tr>
<tr>
<td>Significant</td>
<td>6</td>
<td>Customer experiences discomfort.</td>
</tr>
<tr>
<td>Major</td>
<td>7</td>
<td>Customer dissatisfied.</td>
</tr>
<tr>
<td>Extreme</td>
<td>8</td>
<td>Customer very dissatisfied.</td>
</tr>
<tr>
<td>Serious</td>
<td>9</td>
<td>Potential hazardous effect.</td>
</tr>
<tr>
<td>Hazardous</td>
<td>10</td>
<td>Hazardous effects.</td>
</tr>
</tbody>
</table>
Table 3. Occurrence guidelines for design FMEA (1-10 qualitative scale)

<table>
<thead>
<tr>
<th>Effect</th>
<th>Rank</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Almost never</td>
<td>1</td>
<td>Failure unlikely. History shows no failure.</td>
</tr>
<tr>
<td>Remote</td>
<td>2</td>
<td>Rare number of failures likely.</td>
</tr>
<tr>
<td>Very slight</td>
<td>3</td>
<td>Very few failures likely.</td>
</tr>
<tr>
<td>Slight</td>
<td>4</td>
<td>Few failures likely.</td>
</tr>
<tr>
<td>Low</td>
<td>5</td>
<td>Occasional number of failures likely.</td>
</tr>
<tr>
<td>Medium</td>
<td>6</td>
<td>Medium number of failures likely.</td>
</tr>
<tr>
<td>Moderately high</td>
<td>7</td>
<td>Moderately high number of failures likely.</td>
</tr>
<tr>
<td>High</td>
<td>8</td>
<td>High number of failures likely.</td>
</tr>
<tr>
<td>Very high</td>
<td>9</td>
<td>Very high number of failures likely.</td>
</tr>
<tr>
<td>Almost certain</td>
<td>10</td>
<td>Failure almost certain.</td>
</tr>
</tbody>
</table>

4.4. Detection

Here we have to distinguish between two types of detection. On one hand we have to identify Current Controls (design or process).

Current Controls (design or process) are the mechanisms that prevent the cause of the failure mode from occurring or which detect the failure before it reaches the Customer. The engineer should now identify testing, analysis, monitoring, and other techniques that can or have been used on the same or similar products/processes to detect failures. Each of these controls should be assessed to determine how well it is expected to identify or detect failure modes. After a new product or process has been in use previously undetected or unidentified failure modes may appear. The FMEA should then be updated and plans made to address those failures to eliminate them from the product/process.

The other thing is to assess the probability that the proposed process controls will detect a potential cause of failure or a process weakness. Assume the failure has occurred and then assess the ability of the Controls to prevent shipment of the part with that defect. Low Occurrence does not mean Low Detection - the Control should detect the Low Occurrence. Statistical sampling is an acceptable Control. Improving Product and/or Process design is the best strategy for reducing the Detection ranking - Improving means of Detection still requires improved designs with its subsequent improvement of the basic design. Higher rankings should question the method of the Control.

The ranking and suggested criteria are shown in table 4: Detection ranking and suggested criteria.

Table 4. Detectability guidelines for design FMEA (1-10 qualitative scale)

<table>
<thead>
<tr>
<th>Effect</th>
<th>Rank</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Almost certain</td>
<td>1</td>
<td>Proven detection methods available in concept stage.</td>
</tr>
<tr>
<td>Very high</td>
<td>2</td>
<td>Proven computer analysis available in early design stage.</td>
</tr>
<tr>
<td>High</td>
<td>3</td>
<td>Simulation and/or modeling in early stage.</td>
</tr>
<tr>
<td>Moderately high</td>
<td>4</td>
<td>Tests on early prototype system elements.</td>
</tr>
<tr>
<td>Medium</td>
<td>5</td>
<td>Tests on preproduction system components.</td>
</tr>
<tr>
<td>Low</td>
<td>6</td>
<td>Tests on similar system components.</td>
</tr>
<tr>
<td>Slight</td>
<td>7</td>
<td>Tests on product with prototypes and system components installed.</td>
</tr>
<tr>
<td>Very slight</td>
<td>8</td>
<td>Proving durability tests on products with system components installed.</td>
</tr>
<tr>
<td>Remote</td>
<td>9</td>
<td>Only unproven or unreliable technique(s) available.</td>
</tr>
<tr>
<td>Almost impossible</td>
<td>10</td>
<td>No known techniques available.</td>
</tr>
</tbody>
</table>

4.5. Risk Priority Numbers (RPN)

The Risk Priority Number is a mathematical product of the numerical Severity, Probability, and Detection ratings:

\[
RPN = (\text{Severity}) \times (\text{Probability}) \times (\text{Detection})
\]

The RPN is used to prioritize items than require additional quality planning or action.

4.6. Actions

Determine Recommended Action(s) to address potential failures that have a high RPN. These actions could include specific inspection, testing or quality procedures; selection of different components or materials; de-rating; limiting environmental stresses or operating range; redesign of the item to avoid the failure mode; monitoring mechanisms; performing preventative maintenance; and inclusion of back-up systems or redundancy.

After that we have to assign Responsibility and a Target Completion Date for these actions. This makes responsibility clear-cut and facilitates tracking.

Update the FMEA as the design or process changes, the assessment changes or new information becomes known.

5. FMEA OF AUTO COOLING FAN MOTOR

To achieve planned goal is to get lifetime of cooling fan motors from 500 hrs to 3000 hrs, all parts from the fan motor’s – rotor, bearings, collectors etc, are analyzed from the aspect of importance for the motor functionality. Complete FMEA analysis is done for every mentioned part and actions necessary for lifetime improvement are applied. One part FMEA analysis of the applied improvements is shown in the Table 5.
After definition of necessary actions, redesign of the electrofans is applied and experimental testings are started.

6. CONCLUSION

In accordance to above note it can be concluded:
The most important aims of the FMEA, of the fan motors as a part of the car cooling system SUS, as key substructure:
- through lab investigation, which bartered road investigation, receive systematic identification of all possible causes combinations which lead to unwonted event;
- determinate of parts or operations which most seriously affect on certain reliability measurement and application need for measurement improvement;

With FMEA it can be concluded in which direction development need to go – in the construction or in the production process of the fan-motors, for increasing of working time from 500 to 3000 hours, and except invest in development and material quality control improvement, parts and subparts, new equipment for production, this product does not charge – input price increasing for raw materials (material and parts).

REFERENCES


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