Failure mode and effect analysis (FMEA) is an analytical technique used to identify potential failure modes and their associated causes. Specifically, a FMEA can find the weaknesses in product designs and manufacturing processes before the design and process are realized, either in prototype or mass production. Originally formalized by the National Aeronautics and Space Administration (NASA), FMEA has been used by major automotive companies and electronics manufacturing services (EMS) providers.

**FMEA Basics**

The three types of FMEA are system FMEA, design FMEA and process FMEA. This article emphasizes process FMEA. FMEA is an applied form of problem solving and can be used in a wide range of engineering disciplines. The steps to conduct FMEA activities (Figure 1) are as follows:

- Identify the intended technologies, problems or products
  - new systems, products and processes are designed
  - existing designs or processes are changed
  - carry-over designs and processes are used in new applications or for new environments.

- Form FMEA team. An ideal FMEA team should include representatives from all affected activities: design, manufacturing, assembly, quality, reliability, service, purchasing, testing and suppliers.

- Document the FMEA number, date and revision. To maintain FMEA as a “living” document, the FMEA number must include the date when the FMEA was initiated and when it was updated.

- Generate process flow chart. Typically, the process flow chart is a result of manufacturing engineering activities around the line layout (sequence of events and demand flow technology practices) and line balancing. The process flow chart is required for FMEA; FMEA cannot start unless the process flow is established and the process flow will likely not change.

- List potential failure modes, effects, causes and process controls for each operation
  - Potential failure modes. For each process function in the process flow, the potential failure modes should be determined. For a surface-mount process, one example could be solder balling based on the experience of engineering around solder paste handling, type of solder mask used and the land pattern design of the component in question.
  - Potential effects of failure. For each failure mode, one or more potential effects should be listed. For example, solder balling could...
potentially impact long-term reliability, so it should be noted under potential effects.

- Potential causes of failure. For each failure mode, one or more potential causes should be listed. For example, solder balling could be due to land pattern design or other process issues such as excessive moisture in the paste and paste volume control.

- Current process controls. This factor is based on current methods to detect failure modes and prevent root-causes. For example, the current process control to detect solder balling could be automatic optical inspection or a well-documented handling procedure for solder paste.

• Rank severity, occurrence and detection
  - Severity is an assessment of the seriousness of the potential failure mode’s effect on the product. A ranking of 10 is most severe, and 1 is no effect.
  - Occurrence is how frequently the specific failure cause or mechanism is projected to occur. A ranking of 10 is considered almost certain and can be related to the process capability (Cpk) being 0.33 or ppm of >10,000.
  - Detection assesses the probability that the proposed process controls will detect the failure mode. A ranking of 10 is equivalent to not detecting, and 1 is equal to detecting defects that passed the current process control.

• Calculate the risk priority number (RPN). RPN is a product of multiplying severity, occurrence and detection ratings. It is used to rank the potential process weakness, so possible actions can be considered to reduce critical process variation and make the process more robust. Corrective action should be first directed at the highest ranked concerns and highest ranked severity items. The worst-case scenario would be 1,000 and the best-case scenario would be 1. The best approach on where to start should be based on a pareto chart of RPN and selecting those items that fall below a cumulative rating of 80 percent.

• Recommend action with responsibility and completion date. The intent of process actions is to reduce one or more of the rankings. Consider remedial actions whenever: an effect of a failure mode has a severity ranking of 9 or 10; a product of severity and occurrence rankings of failure mode/cause combination is high; or a combined RPN is high. After corrective actions have been identified and implemented, allow for a period of stabilization, then review and revise the resulting occurrence, severity, and detection and risk priority ranking.

FMEA Application

FMEA is meant to be a “before-the-event” action, not an “after-the-fact” exercise. To achieve the greatest value, FMEA should be done before a process failure mode has been unknowingly planned into the product. The five phases of product development (Figure 2) include: plan and define; design and development; process design; pre-production; and mass production.

As an EMS provider, our company uses FMEA for manufacturing process plan and control. Early involvement of FMEA is key to building quality into our products, documenting the process and continuously improving the process. For most of our customers, after the design and manufacturing processes are finalized, their products are transferred to our manufacturing center where the FMEA technique is used.

Example FMEA for a hand held product

A FMEA meeting is held after the new product introduction (NPI) launch meeting. A FMEA team is formed, which includes the production supervisor, process engineer, product engineer, test engineer, quality engineer, materials/buyer and program manager. The quality engineer leads the FMEA team.

The goals of the first FMEA meeting are to emphasize quality control points into the initial manufacturing process instruction and test
process instruction (MPI/TPI) and also to have the team gain better knowledge of the product. The typical activities during and after the meeting include:

• The process/manufacturing engineer presents the process flow chart operation by operation (only for PCB assembly at that time). In the flowchart, the process function and requirements for each operation are defined.
• The team works together to list all potential failure modes, potential effects, potential causes and current process controls for each operation and ranks them by risk priority number. For example, in the potential failure mode of missing solder paste in the screen print operation, the current process controls are stencil design, clean the stencil periodically, visual inspection, machine preventive maintenance (PM) and paste viscosity checking. The process engineer includes all current control points into the initial MPI, such as stencil design study, specifying the frequencies of stencil clean and visual inspection, and solder paste handling.
• The FMEA team audits the current production line and reviews the current line setup and preventive maintenance procedures against the current control points in the FMEA document. As an example, the audit team recommended that the dry box should be relocated next to the fine-pitch placement machine to handle moisture-sensitive components.

The follow-up FMEA meeting

The follow-up FMEA meeting was held after the post-NPI build. In this meeting, the current process control was reviewed against the quality report of the NPI build. The team re-ranked risk priorities, and the top three defects were highlighted for each operation. Recommended actions, responsibilities and target completion dates were also assigned. All initiators are responsible for implementing effective follow-up programs to address all recommendations.

For the surface-mount process, the top two defects were solder ball defect and tombstone defect. The following recommended actions were assigned to the process engineer:

• For the solder ball defect, review the stencil design; review the reflow profile and check the reflow PM record; check the screen printing accuracy and check the pick-and-place machine placement accuracy.
• For the tombstone defect, check the screen printing accuracy; check pick-and-place machine placement accuracy; check the reflow direction; and investigate the possibility of contamination on the termination.

The process engineer’s investigation showed that a rapid rise in the reflow temperature was the cause of the solder ball defect. A contaminated termination was a potential cause for the tombstone defect. A design of experiment (DOE) was planned for the next design validation testing build. The DOE found that one vendor's component had a higher potential for tombstone defects. A corrective action request was issued to the vendor for further investigation.

Whenever a change is being considered to a product's design, application, environment material or manufacturing or assembly process, the FMEA document must be updated. A FMEA update meeting in NPI is an ongoing activity until the product is ready for mass product build.

FMEA activities in mass production

As a process improvement history document, the FMEA is always transferred to the mass production site when the product goes to launch. The FMEA team at the mass production site reviews the FMEA document to understand the current control points of each operation before starting mass production. The FMEA team also conducts the process audit for the production line. All open action items from the NPI FMEA are carried over to the mass production site.

Pick-and-place machine accuracy was one concern after the process audit. The equipment department had to verify the Cp/Cpk of the placement machine. Training to handle misprinted boards was also conducted.

The FMEA team closely monitors the first pilot build. Production line qualification is conducted in parallel when possible. After pilot build, a FMEA meeting is conducted. The team reviews current quality controls against the pilot run's quality report, and the top three defects of each operation are addressed.

FMEA is an ongoing effort and a continuous improvement process. The FMEA document should always reflect the last design level, as well as the latest relevant actions, including any actions that occur after the start of production.

Conclusion

Utilizing FMEA increases the ability of an EMS provider to reduce time-to-market by identifying risks early in the project. In addition, FMEA uses a variety of experts to examine the manufacturing process from all sides, which leads to continuous manufacturing improvements.

The recommended actions should be positive corrections with quantifiable benefits. To reduce the probability of occurrence, process and design revisions may be required. An action-oriented study of the process by using statistical methods should be implemented with continuous feedback of information to the appropriate personnel for process improvement and defect prevention.

Bibliography


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