Process Quality Metrics for Mechanical and Electrical Production Line

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Abstract

In order to applying defects per million opportunities (DPMO) to mechanical and electrical industries, this paper gives a clear and effective way to define defect opportunity, which is a key point in deploying DPMO. This paper is based on a project of establishing a quality index system for Siemens Electrical Drives Ltd. Based on the on-site investigation and IPC-7912 calculation of DPMO and manufacturing indices for printed circuit board assemblies which gives a clear definition on DPMO defect opportunities for printing board assembly line, this paper proposes the rules to recognize, categorize and define the defect opportunities in motor production line by the joint efforts of the project members and the engineers. Component opportunity, assembly opportunity and operation opportunity are brought up to summarize the defect opportunities in the mechanical and electrical line. A set of defining rules is given to define according to the feathers of different lines. It has proven by Siemens facility that the defining rules are effective in measuring process quality for different sizes of motors. It can serve as a reference for other mechanical and electrical enterprises to define defect opportunities.

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Key words: process quality management; defects per million opportunities; mechanical and electrical production line; defect opportunities

1. Introduction

Process quality is the guarantee for good product quality. The establishment of process quality indicators is the basis for process quality control. The most commonly used process quality indicators are process final yield (PFY), first time yield (FTY), rolled throughput yield (RTY), Defects per Unit (DPU) and Defects per Million Opportunities (DPMO). They are all effective indicators to measure process quality.

DPMO refers to the average defects per 1,000,000 defect opportunities. Compared to PFY, FTY, RTY

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and DPU. DPMO adopts the concept of defect and defect opportunity, which enrich the content of the measurement, better reflect the process quality and promote the continuous improvement.

IPC-7912 Calculation of DPMO and Manufacturing Indices for Printed Board Assemblies is officially released in 2000 and gains wide recognition among quality experts and practitioners from various fields. It classifies defect opportunities into three kinds: component defect opportunity, placement defect opportunity and termination defect opportunity. This classification and defining of the defect opportunities properly help measure the process quality of electronic industry.

But the IPC-7912 definitions no longer apply to mechanical and electrical industries, as George pointed out, DPMO has become one of the most important indices of six sigma, the application scope of this indicator is relatively less [1]. That is because, when the DPMO definition of IPC-7912 is applied to other industries, it is not effective any more, as the defect opportunity defining and classification method does not apply to other industries. For example, in the mechanical and electrical industries, the operation procedures are much more complex than those of electronic industry, whose main work is placing and welding. Not only assembly work but also operation jobs are involved in mechanical and electrical industries. Moreover, the job is not repetitive, that is to say, the operations are different among the working units in mechanical and electrical industries. Companies usually do not have the ability to define DPMO according to their own production features, which is also one reason of little application of DPMO in non-electronic industry. Lei, etc (2001) [2] made research and introduced DPMO to a production company, but the application is also limited to assembly work and do not give out the defining method for the production line.

2. DPMO and its advantages

2.1. DPMO

Compared with other quality measurement indicators, DPMO (Defects per Million Opportunities) can not only reflect the process quality, but also can compare the quality of different complexity, like different enterprises, different divisions, different production lines. Many companies have proven the benefits of DPMO index system [3].

IPC-7912 Calculation of DPMO and Manufacturing indices for Printed Board Assemblies makes a clear definition of DPMO. DPMO refers to the defects per 1,000,000 defect opportunities. See below (1) for the calculation of DPMO [4]:

\[
DPMO = \frac{D \times 1,000,000}{U \times O}
\]  

(1)

Where, D=defects, U=units and O=defect opportunities per unit.

Harry and Schroeder explain the formula from another perspective [5]: DPMO is the ratio of defect rate and the number of the key quality characteristics, multiplied by one million.

The following formula (2) gives the relationship between DPMO and DPU [6].

\[
DPMO = \frac{DPU \times 1,000,000}{OA}
\]  

Where OA=average defect opportunities per product

In the formula, defect refers to the quality characteristics which fail to meet the customer requirements or the technical requirements.

Defect opportunities refer to the maximum potential errors occurred when operating or assembling a product. In general, the more the procedures are, the more complex a product is, the more the defect opportunities are. For example, when welding 5 coils, the defect opportunities are 5; when welding 50 coils, the defect opportunities are 50.

Defect opportunities are potential errors. Defects are errors occurred. The introduction of defects and defect opportunities enrich the quality indicators and are beneficial for the measurement and improvement of process quality. The precise definition of defect opportunities is very important. If the defect opportunities are defined less than they should be, the indicator is ineffective as the process quality is
overestimated. If the defect opportunities are defined more than they should be, the process quality would be underestimated.

When applying DPMO in process quality, the following requirements should be met. First, the process must be in control, that is to say, there should be no defects which are caused by systematic reasons. Second, the sample size should be large enough. Third, the definition of the defect opportunities should have clear meanings.

2.2. Advantages of DPMO

First, DPMO can evaluate the process quality level of different product and service. The introduction of the concepts of defect and defect opportunity make it possible to assess the process quality of different complexity. DPMO has become the common, universal and reasonable measurement of process quality for different products and procedures. For example, it is not persuasive to compare the quality level with the index of process final yield, as it is unfair and not scientific. But if applying DPMO, the results would be believable due to the consideration of complexity.

Second, DPMO is an indicator of process capability. Previous indicators focus on the product quality. DPMO examine the whole process, every procedure and operation. Thus, it can reflect the performance of the whole production line and bring forward the improvement opportunities.

Third, DPMO can be applied flexibly. DPMO can be applied to a key process, automatic welding equipment or a work unit. It is not confined to a product or a facility. Companies can also examine the quality from the following aspects: the whole company, every production line and part supplier etc.

In all, DPMO can examine every defect which may influence the product performance or lead to the customer dissatisfaction. Moreover, DPMO put all defects into equal position. And thus it reflects everything that may lead to customer dissatisfaction, not matter the defect is big or small, the results are severe or not. DPMO reflects the process capability and embodies the concepts of continuous improvement and customer orientation.

3. The definition of defect opportunities in mechanical and electrical companies

Mechanical and electrical products refer to the various types of production equipments or household appliances made by mechanical, electrical or electronic devices like farm machinery, electrical appliance, electronic equipment and other similar products. Both operating work and assembling work are involved. The output can either be large or small batch. Refrigerator, transmission and motors are all mechanical and electrical products. This paper will define DPMO defect opportunities in the mechanical and electrical companies.

This paper is based on the project DPMO quality index system establishment for Siemens Electronic Drive Ltd. The manufacture and quality engineers together developed the DPMO quality system and the system had already been used in the daily operation. By the further examination and evaluation by the project team, it is an effective definition method for the measurement of the process quality. The defining method of DPMO brought up in this paper is based on the definition concept of IPC-7912, and is an expansion to its application scope. The defining method in this paper can serve as a reference for the manufacturing industry.

Based on the flow chart of the production line, after detailed investigation and data analysis, according to the work instruction and FMEA, the defects in the workshop are classified into three categories: component defect opportunity, assembly defect opportunity and operation opportunity. Below is the guidelines of the defining the defect opportunities which suit the characteristics of the production line.

1. The guideline of defining defect opportunity:
   a) Assign one defect opportunity to one part.
   b) The bulk materials will not make a defect opportunity.
   c) A continuous operation (assembling) can make one operation (assembly) defect opportunity.
Overall defect opportunity should be the sum of the component defect opportunity, the assembly defect opportunity and operation defect opportunity.

The comparison of DPMO should be based on the same approach of defect opportunity defining.

Inspection will not form a defect opportunity.

2. Component defect opportunity defining rule

Rule 1: A part may have several kinds of defects. Assign one defect opportunity to one part, not to one kind of defect.

Rule 2: When operating or assembling a product, if the batch of parts shares the same defects, define one defect opportunity for the whole batch. E.g. mica expiration.

Rule 3: Define no defect opportunity to the bulk materials. Bulk materials refer to the packaging materials, tape, tie bags and so on.

Rule 4: To avoid the duplicate defining, when assembling, define no defect opportunity to the pre-installed components.

3. Assembly defect opportunity defining rule

Rule 5: When assembling, if the wrong direction or wrong position may occur to a part, no matter how many chances of errors may take place, only define one defect opportunity to one part.

Rule 6: Normally, when welding, assign one assembly defect opportunity to one welding operation.

4. Operation defect opportunity defining rule

Rule 7: Normally, if there are m kinds of operation defects, define one defect opportunity for each kind. There should be m defect opportunities.

If the defect is dimensional problem, refer to rule 8.

If the defect is wrong order problems, refer to rule 9.

If the reason for the defects cannot be distinguished, refer to rule 10.

Rule 8: when there are n kinds of dimensional problems, if the dimensional problems are caused by one operation, define one defect opportunity. If the dimensional problems are caused by several different operations, define n defect opportunities.

Rule 9: When the order problems take place on one kind of part, define only one operation defect opportunity. Note that this rule applies to one kind of part.

Rule 10: In one procedure, if the same defects take place in n operations, define n defect opportunities. But if the operation defects cannot be distinguished easily, define only one operation defect opportunity. E.g. Bumps may occur to stator coil when it is put into or out of the operation box. As the operation box is closed, it is difficult to distinguish the bump is caused by putting into or taking out. So to all the bumps in the process, define only one defect opportunity.

Rule 11: When assembling apart and potential damage may occur to another part, define one operation defect here. E.g. knocking the coil when assemble the shaft.

In all, in the mechanical and electrical enterprises, all defects can fall into three categories: component defect opportunity, assembly defect opportunity and operation defect opportunity. The above rules are developed based on the concept of DPMO in IPC-7912 and focus on the production and assembly characteristics of mechanical and electrical companies.

4. Case study

The project team uses the rules in section 3 and defines the defect opportunity for three workshops in the Siemens Electronic Drive Ltd. Due to length constraint; this section will introduce the defining rules application in part procedures of motor welding: coiling winding, hot pressing and shape forming. The chosen product is motor 1LA4562-2CN80-Z. Please refer to the Fig.1; one for the flow chart at the end of the paper. These are the preliminary steps of making a rotor of 60 coils.
Work description of the procedures: Coil winding is to insert hardened belt between the flat copper wires and fix them together with tapes, according to the requirements of the specification. The output of the procedure is the shuttle-type coil. Hot pressing is to press the coil under required temperature and pressure. Shape forming is to form the coil into special shape per the requirements of the drawing.

The defect opportunity defining is shown in table 1 the defining of defect opportunities in the welding workshop, which is attached to the end of this paper. Below explains the defining process in details.

Table 1. The Defining of defect opportunities in the welding workshop

| Procedure          | Defect Opportunity                                               | Defect Type      | Defect Opportunity |
|--------------------|------------------------------------------------------------------|------------------|--------------------|
| Coil winding       | The expiration and width error of hardened belt                  | Component defect | 1                  |
| Coil Welding       | Internal length error                                            | Operation Defect | 1                  |
| Coil Welding       | Incorrect number of turns                                        | Operation Defect | 60                 |
| Coil Welding       | Incorrect inserting position of the hardened belt                | Assembly Defect  | 120                |
| Hot pressing       | The expiration and width error of hardened belt                  | Component Defect | 0                  |

The expiration and width error of hardened belt—1 defect opportunity is assigned to the defect. The hardened belt used in the coil winding is the same batch. That is to say, if one hardened belt expires, the whole batch expires. So per rule 2, define one defect opportunity to one batch.

The width error of the hardened belt is dimensional error and is completely different from the expiration error. But per rule 1, due to the errors taking place to one component, only one defect opportunity is assigned to the component.

Internal length error—A certain length of the copper wire should be set aside for follow-up procedure welding. The internal length error refers to the length set aside does not meet the requirement; it may be caused by the wrong reading of the drawing, or wrong measurement. But the key point is that for one batch, the operators only measure the length once. So they are all done by one continuous operation. So per rule 2, although there are 60 coils, only assign one defect opportunity here.

Incorrect numbers of turns—The 60 coils share the same number of turns. But when winding, each coil is wound respectively and the operator count the turns for each coil. So the turns of the 60 coils is decided by 60 operations and the defect opportunities should be 60. This and the last example can give a

Incorrect insertion of the hardened zone—There should be two hardened zones put into each coil.Inserting each hardened zone is an independent operation. So per rule 2, define 120 defect opportunities for the 60 coils here.

In the hot pressing procedure, the width error and expiration is found. They are the missed errors in the inspection. As the defect opportunity is defined is the coil winding procedure, per rule 4, no defect opportunity will be assigned here.

Rule 3 is also reflected here. No defect opportunities are assigned to bulk materials.

These are only simple examples of the defect opportunity defining. The project team defines the defect opportunities of all the production line of the three workshops in the Siemens Electronic Drive Ltd. The
team also develops a calculator to examine and figure out the process quality level of every production line and different products. The calculator has been applied to the daily quality management in the company to examine the process quality level of each production line and each product.

5. Conclusions

This paper brings forward the defining method of DPMO in mechanical and electrical production line on the basis of the definition of DPMO in IPC-7912. This method solves the problem of comparing process quality of products of different complexity. With the indicator developed by the defining of the defect opportunity, the well-trained operators and effective calculation of the defect data, the process quality can be reflected effectively. This defining method has been applied to the enterprise, and it has been proven that the defining method sum up the various problem in the production line and examine the process quality. At the same time, it compares the motor production line of different complexity. This defining method serves a valuable reference to the manufacturing enterprises.

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