Total Quality Control on Printed Circuit Board Assembly Process

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Abstract. *Surface Mount Technology is used widely nowadays in the manufacture of pirnted circuit boards. This article explains how quality problems arising from this technology are tacked in an organization via the implementation of a Total Quality Control system.*

1. Background Information

Philips Hong Kong Ltd.--Consumer Electronics Factory (CEF Ltd.) is a factory in Hong Kong owned by Philips Electronics N.V., a multi-national enterprise registered in Netherlands with over 100 years of history which operates a large spectrum of business ranging from military, aerospace and medical equipment, lighting, domestic appliance, consumer electronics, to communication system. Operation of CEF Ltd. includes the manufacture of consumer products such as portable radio cassette recorders, compact disc players, telephones, answering machines, etc. The manufacturing process in CEF Ltd. can broadly be divided into two areas, namely chassis assembly and encasing. Chassis assembly deals with the production of printed circuit boards (PCB's), while encasing deals with complete set assembly, alignment, testing and packing. Most quality problems in encasing can be identified and solved in the stage of procurement of incoming materials, or during the assembly and inspection proceses. Causes of quality problems in chassis assembly, mainly soldering faults, however, cannot be easily identified. Such faults induced a lot of subsequent rework in the manufacturing process. Even worse is that if these faults are not filtered off before the products reach the customers, malfunction of the products will seriously damage the company's image. In view of this situation, in 1991 the company started a project on implemention a process control system for manufacture of PCB's using a Total Quality Control (TQC) approach, aiming to eliminate causes of soldering faults and improve the quality of products. In this article we shall explain the details.

2. PCB Assembly Processes in CEF Ltd.

In CEF Ltd., PCB's are manufactured using both through hole technology and surface mount technology. In through hole technology, axial-leaded components are pre-taped in the sequence of insertion and then inserted automatically by a machine into the holes on the PCB board. After that, radial-leaded components are inserted. Soldering is then performed on the other side of the board. As for surface mount technology, there are three types of assemblies:

Type I. Pure surface mount device (SMD) placement, where only SMD's are used (on one or two sides of the PCB);

Type II. Mixed placement, with leaded components on one side and SMD's on the

other (solder) side of the PCB; and

Type III. Mixed placement, with leaded components on one side and SMD's on both sides of the PCB.

Type II surface mount assemblies can be made using wave soldering only and they are the easiest to manufacture among the three types, but Type III assemblies are the most commonly used especially for high-density package equipment.

3. TQC in CEF Ltd.

In CEF Ltd., all products are developed by project teams. A project team comprises of members from various functional departments and is headed by a project manager. In 1991, after the top management decided to implement a TQC system in CEF Ltd., a Chief Engineer was appointed as the TQC Project Leader (TPL), who received support from the Management Team regarding the strategy and the direction of the TQC project, company-wide involvement, priority setting for assignments, resolving conflicts between different parties and control of the project. The TPL reports directly to the Engineering Manager on all issues relating to the TQC project. On the basis of the activities carried out in CEF Ltd., two working teams, namely the Process Control Team and Design Control Team, both chaired by the TPL, are set up. The Process Control Team consists of the Process Engineer, the Production Engineer, the Maintenance Engineer and the Production Supervisor as team members and operators and technicians as *ad hoc* members, while the design control team consists of the Process Engineer, the Design Engineer and the CAD Library Manager as team members. After these two teams were set up, the Engineering Manager together with the TPL reviewed the resources available to the teams, established operating procedures and allocated roles to members in the teams, established ground rules so that teamwork could be carried out effectively, and defined the work tasks needed to be done by the teams and allocated responsibilities to individuals. A Management Monitoring Committee (MMC) was also set up. This Committee was chaired by the General Manager, and consists of the Engineering Manager, Development Manager, Material Manager, Production Manager, Quality Manager, a Project Manager and the TPL as members. The TPL was requested to report the progress of the TQC project to the MMC on a regular basis.

3.1 Design Control Team

The Design Control Team is responsible for the improvement, enhancement and realization of the design control system in the company. In the manufacture of PCB's, it is well-known that the design of the board and the design of the assembly process both play important roles in achieving good quality products.

There are general rules adopted in the design of PCB's [1]. For wave soldering [3], in general larger solder pads and larger separation between components are needed in order to have good solder flow and to prevent the occurrence of bridging. Factors such as placement direction of components, pad dimension, component shape, lead geometry, material of the board, etc., are taken into account during the design. The board must be free from large cut-outs or holes (with diam>4mm, say) from which solder will penetrae to the other side of the board. During wave soldering, the wave pressure must be sufficiently high to eliminate the shadowing effect caused by the surface tension on the non-wettable or non-wetted surface and to eliminate skip joints. On the other hand, an excessively high wave pressure could push the solder through the openings on the board and causes solder flooding.

Automatic insertion of conventional components began in late 1970's, and the process itself is quite sophisticated nowadays. Yet, in order to have good results, both the circuit layout and the sequence of insertion must be well-designed. For example, the holes for leads must be appropriate to ensure insertability, good clamping and the absence of open joint. The sequence of insertion of components and the fly-back direction of the insertion head must be designed to avoid the insertion head from hitting the inserted components, and at the same time produce a sufficiently high efficiency of insertion. The orientations of components must be designed to optimize the efficiency of insertion and service-ability of the final product.

Due to constraints such as technical restriction on electro-static discharge path routing or architectural restrictions on the position and orientation of band switches, designed rules sometimes cannot be 100% conformed. Nevertheless, the design quality of a PCB can be indicated by a 'predicted design defect rate' which is calculated by extracting known defect rates of similar circuitry layout from a massive data bank.

In CEF Ltd. the product creation process is broken down into stages marked by milestones. Each stage has its specific objective and expected quality output, and in each stage the quality of PCB layout design is monitored carefully. A milestone can be passed only on approval of the management team. Action must taken for any non-conformance, and a target date for improvement is set.

The quality performance of PCB design is reviewed periodically in meetings. Reinforcement actions will be imposed on those who repeatedly fail to meet the targets, and rewards are given to high-performers.

3.2 Process Control and Monitoring System

The Process Control Team's role is to establish a system to control the production process as well as to improve the process. Well-known tools such as SPC (statistical quality control), QFD (quality function deployment), FMEA (failure mode & effect analysis), experimental design (including Taguchi methods) and fish bone (cause-and-effect) diagrams are used whenever appropriate. Furthermore, defect rates are logged and analysed.

The objective of monitoring a process is to detect deviation and to take appropriate correction actions when necessary. Interventions should not be considered as fire fighting actions only but should also have a preventive nature. In 1993 Philips established four control loops around the production process in order to achieve (a) equipment control, (b) shop floor control, (c) process improvement and (d) innovation in the production process. These four control loops are briefly below.

(a) Equipment control. In an actual process, the material is transformed in a number of steps into the product by means of equipment and tools. The Team had established a 2-way data exchange channel between the shop floor controller and the system that generates manufacturing recipes, so that the shop floor controller can set the equipment parameters accordingly in order to execute the manufacturing recipe.

(b) Shop floor control. The Team considers order flow, material flow, equipment utilization and quality as important aspects in shop floor control. Order flow is the result of change-over of products, and a production system should be flexible enough to adapt to such changes. Since CEF Ltd. produces a large varity of products which have different PCB width, different PCB thickness and different component packing density, production inefficiency is a hard problem to tackle. We shall deal with this in the Section 4.

(c) Process improvement. In order to improve the process, we need to improve the process definition, process enabling and process release. Process definition and process enabling can be improve by using better metrology concepts, better measurement setup and high precision

instruments. Process release covers the procedures for release of process specification, process equipment, process application and mass production. During the period from 1991 to 1993 the Team had considered and implemented various improvement methods.
(d) Innovation. Necessity for innovation may arise from required narrowing of tolerances, environmental constraints, or competition in the market. Starting from 1991 the Team has worked in this direction and implemented some new methods to control the measurement of parameters, devised new SPC charts for auto-insertion process, and so on.

Experiences obtained from this project show that in order to carry out a project successfully, it is essential to appoint a capable project leader, to define the responsibilities of the staff members concerned clearly and provide them with authorization to take measures, to assign a small project team with high degree of imvolvement of team members, to involve shop workers, to be familialized with the process and the equipment, and to provide training programmes for all staff and workers involved.

4. Technical Aspects for Quality Improvement

4.1 Logistic Arrangement

Production conditions for different PCB's may be different -- for example, the settings on the placement machine depend on the PCB width, the solder jet pressure and pre-heating temperature required depends on the component density, and the appropriate solder wave height depends on the thickness of the PCB board. Applying different parameter settings to different PCB layouts is not a practical solution because it involves frequent resetting of the machines and causes machine down-time. Resetting of machine can be avoided by using a separate production facility for each PCB type, but this requires large capital investment because of the high-mix-low-volume nature of the company's production. Grouping similar products together for large batch production reduces the need for machine resetting, but this arrangement results in a very large amount of work-in-progress which in turn ties up a large amount of capital and storage space. In 1992 a project team was set up to start a project on the construction of an automatic parameter adjustment system which would allow the machine to recognize the identity of the board and adjust the parameters settings automatically to suit the required processing conditions. This project team had spent an enormous effort in investigating possible hardward designs, software programming and equipment required, evaluating their technical capability and prices, estimating labour hours required for implementation and aftercare. Based on the findings and considering the product trend, business growth direction and return on net asset, the MMC decided that automatic paramter adjustment is impractical for CEF Ltd. After prolong investigations and evaluations, in 1992 the Process Control Team suggested that the most practical and economical way of solving the order flow problem is to adopt an appropriate set of parameter setting for all PCB assembly. The quality of soldering can be maintained by adopting design rules with proper design control, process control and incoming material control (see Sub-sections 4.2-4.4).

4.2 PCB Material Quality

The PCB material and components used in CEF Ltd. are purchased from vendors. In early 1993 the Process Control Team enhanced the existing incoming material control scheme to ensure the quality of incoming materials. Detailed check lists for visual inspection, dimension inspection for the PCB's and release criteria for solderability of components were constructed -- items such as material type, flatness of the board, cleaniness of the board,

cracks, board width and length, position and size of the holes, etc., are inspected according to MIL-STD-105D. When non-conforming lots are discovered, the vendor will be informed. The long term strategy is, however keep track of and perform analyses of different types of defect, maintain a good relationship and work together with the vendor to eliminate future occurrence of defects, and CEF Ltd. is now working toward this goal.

4.3 Pre-heating Temperature

In compliance with the environmentl standards, CEF Ltd. has changed over to the use of halogen free materials in many processes. The use of no-clean halogen free flux in wave soldering requires a higher pre-heating temperture. Around April 1993 CEF Ltd. worked together with the pre-heating oven manufacturer to performed experiments on how the oven temperature can be raised. Finally it was decided that a stainless steel cover should be installed onto the pre-heating oven. When the complete cover was installed, the maximum reliazable board temperature increased to greater than 110°C, so that the solder machine can be set at a much lower temperature (below 450°C) but the desired PCB surface temperature can be maintained.

4.4 Choice of Flux

CEF Ltd. is keen on improving the quality of products at the PCB assembly level by using flux with low residue, and also interested in adopting environmental friendly no-clean, halogen free flux. Several fluxes obtained from two local suppliers were tested according to the following procedure:
-- appling the sample flux to a bare PCB and passing it through the wave soldering process,
-- examining the board for wetting or soldering problems,
-- putting the PCB to a environmental test and afterwards determining the level of residue left,
-- performing a 1-day on-line trial to check against potential critical problems,
-- performing a 2-week full application test on a soldering production line,
--setting the machine parameters to be as close to the existing TQC reference as possible,
-- monitoring the soldering performance, and analysing the data obtained.
The results of this test showed that, in terms of solder-ability, the overall defect rates for the fluxes under test do not differ significantly, but a new flux has lower levels of residue and stickness. This halogen free new flux was recommended as a replacement of the existing one.

4.5 Mechanization -- Material Identification System

Material identification is important for manufacture of miniature products, since it is difficult to distinguish and to replace a wrongly onserted miniature component on a dense PCB. In the past, CEF Ltd. did not have a material identification system, and materials were identified visually by the operator. In the past 7 years, it happened several times when wrong cartridges of material was loaded onto the machine, resulted in the whole batch of (several hundred) PCB's being required to be reworked. In July 1992 a team consisting of a process engineer, a process technician and a machine technician was formed to conduct a project on mechanization of material identification in order to minimize wrong onsertion due to human error, to increase the reliability of the manufacturing system and to reduce the labour required in SMD material identification. A new material identification system was completed in 3 months. This system has the following four parts:
(1) Identification Unit -- this unit provides information and means to identify whether trays,

tray holders, parts reels, cartridges and parts are in the correct place. The new equipment used contains a programmable hand held bar code reader, a mobile computer and an RAM pack. Software is required for communication between the decoder and the computer, and for transferring the data base of the supervisor computer to an IBM format.

(2) Data acquisition Unit -- this unit acquires data from a CAD database about onsertion and the components being onserted. The sequence of onsertion is either provided by the placement machine which has a critical path programme installed in it, or is done manually, depending on the complication of the component layout.

(3) Inspection Unit -- the function of this unit is to confirm that trays, parts, etc. are placed in the right place and sequence. A bar code reader is mounted onto the SMD placing machine, and it sequentially reads the registered marks on the trays, cartridges and material reels. Then the identities of components, trays, etc. are compared with data in a data bank to check for correctness.

(4) Alarming Unit -- this unit will alarm workers when parts are misplaced. When data are mismatched, the installed alarm system on the SMD placing machine will be triggered.

5. Results and Conclusion

Two years after the lauch of this project, a final audit was performed in late 1993. The overall defect rate has been decreased from 10000ppm to 3500ppm. Besides the actural achievement in defect rate, a lot of tangible and intangible benefit have been obtained. Now the machine down-time and production cost have decreased, machine up-time, productivity and product transfer-ability have increased. There are better consistency in operation, more transparancy in operation, staff and workers have more job satisfication. Records show that there are less complaints from customers and less service-calls. The company and the brand have better image and better goodwill as reflected from the sales figures and the market share.

The coverage of this project was very wide -- it covered everything from the production design phase to the production realization and industrialization phases. The TQC approach involved over 300 engineers employed in CEF Ltd. In this very complex and large scale project, good leadership and discipline in the organization ae fundamental. During the progress of the project conflicts between employees in the organization was unavoidable, but such conflicts could become manageable and constructive under good management [2].

Because of the ever changing products and increasing demand for quality, maintaining processes in control and improving products and processes is a continuous effort. What is satisfactory today may become inadequate tomorrow. Whatever system adopted must be flexible enough to suit moving targets.

References

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[2] Randolf, W.A., *Managing Organizational Behavior,* Irwin (1989), *New York.*

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