The verification technology for the quality and reliability of parts

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[Summary] Electronic measuring instruments are becoming lighter and smaller through increased use of extremely small electrical parts, especially semiconductor and high-frequency active parts. Additionally, PC boards are becoming increasingly higher count multi-layer, faster and more complex with use of multi-pole, fine-pitch internal connectors. As a consequence, it is becoming increasingly difficult to assure the reliability and quality of parts. Moreover, parts procurement has become globalized, which also increases quality risks. In these circumstances, verification of parts quality at every stage from development through to delivery is critical to assuring selection of high-reliability parts and stable quality during mass production.
This article describes some effective solutions for increasing quality using structural analysis and inspection of parts.

1 Introduction

To assure the reliability of parts purchased for use in products and improve product quality, Anritsu in April 2013 integrated the previously independent Parts Analysis Team and the Quality Assurance Purchasing Team. As a result, we have established a system at the product development process for proactively evaluating parts at every stage starting at the parts selection (Figure 1).

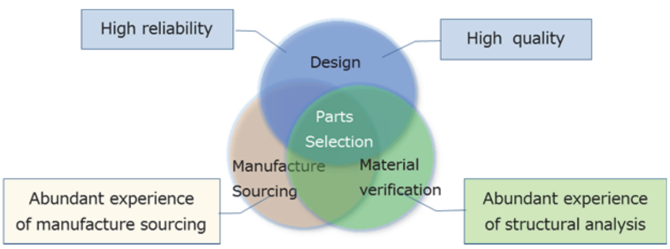


Figure 1 Parts Evaluation System

As we have expanded exports of electronic instruments and food inspection systems to newly industrializing economies (NIEs), there have been an increasing number of product issues due to poor operating environments (contamination, atmospheric pollution, etc.) and inappropriate handling.

The above-mentioned department integration has helped develop parts' quality verification aimed at reducing failure risks by developing systems for selecting parts as well as leveraging experience in parts verification. Quality verification results are fed back to the design and production departments, which also helps improve reliability.

2 Quality Verification System

To assure product quality and reliability, we investigated inherent failure risks from the original parts design selection stage as an effective proactive fault prevention.

As a result, when using new parts, the product development departments now prepare early Design Review 3 (DR3) materials for parts verification and any resulting quality improvements are fed back to the QA department before product release.

Figure 2 shows the quality verification system classified into analysis of good parts during and after development, and fault analysis after mass-production and shipping.

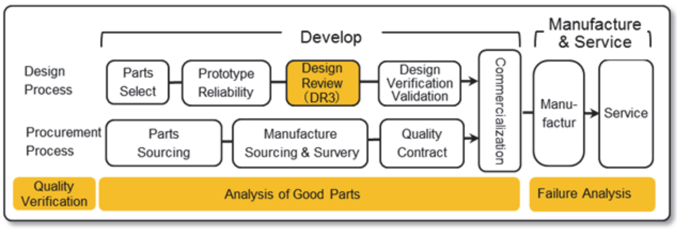


Figure 2 Quality Verification System

Each activity is explained below.

(1) Quality Analysis Points

Analysis of good parts is diagnostic analysis of fault risks under normal conditions. This analysis requires highly specialized knowledge and experience as well as understanding of manufacturing procedures. The reliability test equipment shown in Table 1 is used to reproduce quality and reliability aging phenomena that are then examined using the SEM, EDX, and X-ray CT equipment described below to clarify fault risks. Analysis of new parts is undertaken to develop countermeasures for preventing part faults due to natural aging.

Table 1 Reliability Test Equipment

Environ-mental factors	Assumed aging	Test equipment
Environ-mental aging and elapsed time aging	Temperature related aging	Temperature chamber and dryer
	Humidity related aging	Temperature and humidity chamber
	Sudden temperature change related aging	Thermal shock tester
	Ultraviolet related aging	Weather meter
	Sulfide related aging	Accelerated sulfuration aging tester
Mechanical aging	Vibration related aging	Vibration tester
	Mechanical shock related aging	Drop tester

For example, assuring the functions and quality of the internal patterns of mass-produced PC boards is difficult. Consequently, we use a cross-section analysis at the design stage to determine whether the accuracy of the internal patterns of the circuit boards will be adequate and support consistent quality and sufficient margin for mass production.

(2) Fault Analysis Points

Fault analysis uses a fault tree to systematically analyze the causes and primary factors of fault phenomena, clarifying the true causes. Since part faults occurring at manufacturing and after shipment require the fastest possible clarification of causes, causal analysis and occurrence mechanisms are the main investigation items.

Quick countermeasures to fault occurrences are taken based on the analysis results to minimize the spread of a fault by correcting mass production and thereby suppressing fault recurrence after shipment.

3 Main Inspection Facilities

In-house inspection equipment supports detailed fault analysis at the lowest costs in the shortest possible time and the results are then shared with all related departments in near real-time.

When even more detailed analysis is required, outside laboratories are utilized.

The following sections introduce some of the main inspection equipment available in our internal facility.

3.1 Scanning Electron Microscope (SEM)

Figure 3 shows the scanning electron microscope (SEM). Materials are scanned by an electron beam generated from an electron gun to produce an electron micrograph obtained by detecting secondary electrons radiated from the material and reflected as electrons. Since the SEM can magnify images up to about 20,000 times, it is very useful for detailed examinations of corrosion, cracks, internal damage, and others.

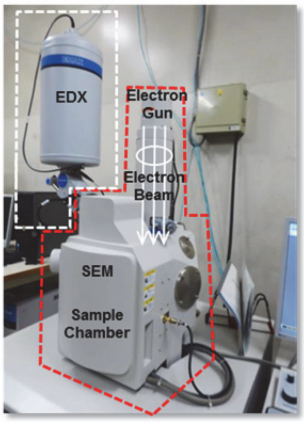


Figure 3 External View of SEM/EDX Equipment

Figure 4 shows a SEM micrograph (150x magnification) of a solder break in a BGA, and of 40-µm tin whiskers (1500x).

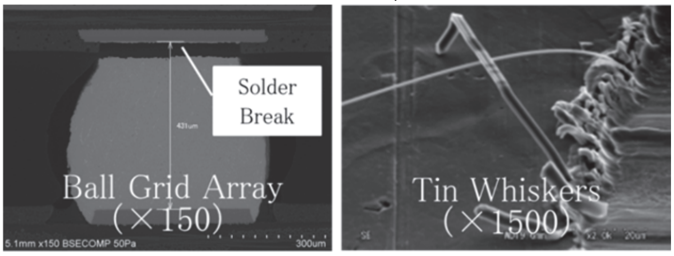
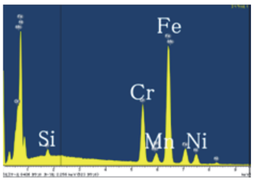


Figure 4 Example of SEM Images

3.2 Energy Dispersive X-ray Spectrometry (EDX)

Energy dispersive X-ray spectrometry (EDX) scans the test material with an electron beam from an electron gun and X-rays (unique to the elements). Radiation from the material is detected to give an instantaneous identification of the composition of the elements. Since EDX uses the same electron gun as an SEM, the procedure can be performed jointly (Figure 3).

EDX can be used to identify the elements of non-organic materials, such as metals, ceramics, etc. Figure 5 shows an example of elemental analysis of JIS SUS304 stainless steel with the results verifying that the material satisfies the JIS standard.



EDX Analysis Results [mass %]

Detected Elements	Si	Cr	Mn	Fe	Ni
Detected Amount	0.7	17.7	0.8	73.1	7.7

Figure 5 EDX Analysis of SUS304 Stainless Material

3.3 Accelerated Sulfuration Aging Test Equipment

This test equipment shortens the time required for detecting metal corrosion caused by sulfur-containing gases, such as hydrogen sulfide (H_2S) and sulfur dioxide (SO_2). Figure 6 shows the equipment.

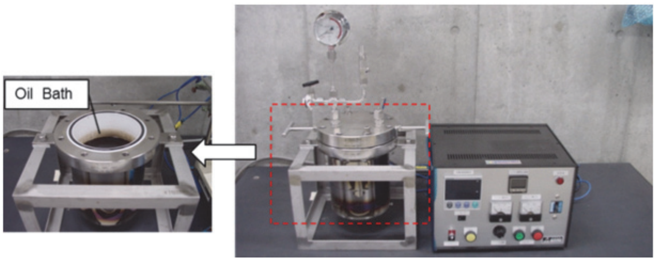


Figure 6 Sulfuration Accelerated Aging Test Equipment

The test is performed by immersing the parts for a specified time in hot oil containing sulfur components. Section 4.5 b shows some accelerated sulfuration aging test results for various chip resistors.

High levels of air pollution in NIEs, such as India, China, Southeast Asian Countries, causes accelerated sulfide corrosion of electronic parts. As a result, evaluation of resistance to sulfurization for new parts using an active gas tolerance index is a key design standard.

3.4 X-ray Computed Tomography (CT) Scanning Equipment

The X-ray CT scanner provides detailed internal examinations of parts by using graphical processing to assemble cross-sectional images obtained by scanning with X-rays in all dimensions into 3D stereoscopic images. Since the internal structure can be observed without physical damage to the part, it is used for direct observation of damage when investigating the validity of a structural design.

It is also useful for examining inherent faults by determining internal structures of parts that the part's manufacturer does not publish. Overall, it is used for the acceptance testing of new parts and for fault analysis.

4 Parts Analysis Examples

The results of parts reliability and quality verification tests are fed-back to the development, purchase, production, and service departments to help with the selection of high-quality and high-reliability parts, which is important in preventing post-shipment aging deterioration and in maintaining long-term parts quality. Some examples of analysis effects are described below.

4.1 Verification of Internal Structure of Multi-layer PC Boards

Figure 7 shows the cross-section of a multi-layer PC board. This cross-sectioning process can be used to determine whether the dimensional accuracy between the multi-layer PC board patterns satisfies the design criteria. It can also be used to evaluate deviations from the design values, and plating quality by providing details of the internal board structure.

The cross-sectional analysis is required when creating a new PC board design or using a special layer configuration. It is used in cooperation with the PC board manufacturers to assure product reliability and quality.

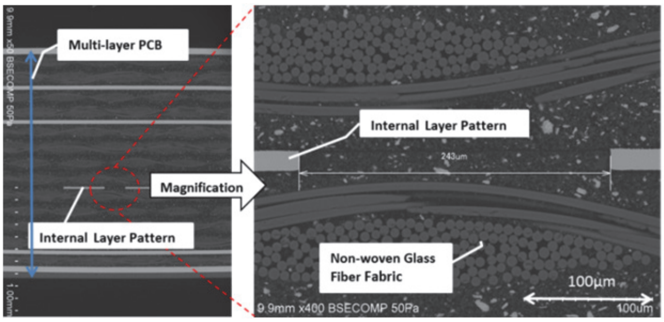


Figure 7 Cross Section of Multi-layer PC Board

4.2 Analysis of Wire Bonding Breakage

RF modules have the potential to be susceptible to breaks in the internal wiring as shown in Figure 8.

Figure 8 Wire Break

Figure 9 shows the wire bonding at the PC board side, comparing a good and bad process. In the bad process the bonding tip is convex compared to concave in the good process.

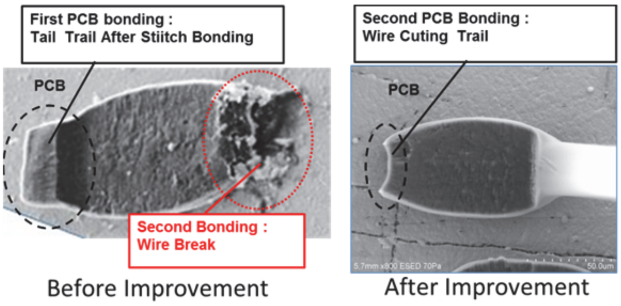


Figure 9 Magnified View of Wire Bonding

Wire bonding is a 2-step connection process and wire breaks are more likely to occur after the second bonding step, depending on which side is done first. At the second bonding step, the concave tip leaves a cutting scar. It would appear that the scarring is from the first bond in bad lots, while it is actually from the second bond.

As shown in Figure 10, in a good process, the angle of the second bond is low helping minimize the tensile stress.

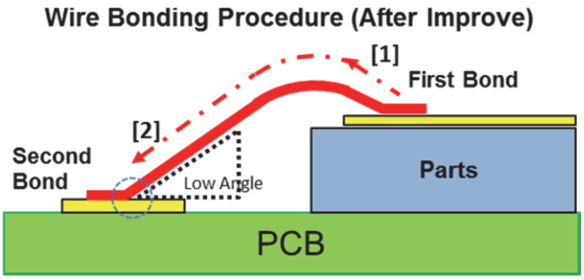


Figure 10 Schematic of Good Lot

Conversely, in a bad process, as shown in Figure 11, the angle of the wire is high from the first bond to the second bond. As a result, the base of the first bond is subjected to high tensile stress, causing the wire clip to potentially break.

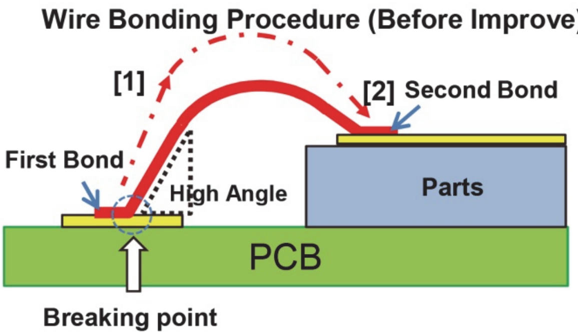


Figure 11 Schematic of Faulty Lot

Sharing these break analysis results with manufacturers has helped stabilize quality by standardizing on the wire bonding sequence.

Wire bonding is widely used in RF assemblies, and this process has been spread throughout the industry as a preferred wire bonding method.

4.3 Analysis of Electrostatic Damage to Semiconductor Switch

As circuit traces become smaller due to the trend towards using lower voltages, immunity to high-voltage electrostatic discharge (ESD) is becoming lower and more ICs are suffering ESD damage. Figure 12 shows an example of using SEM for analysis of damage caused by ESD.

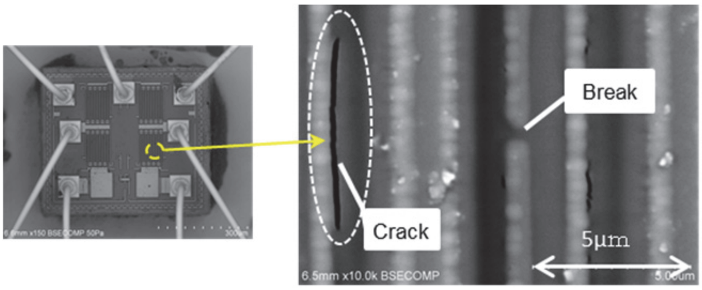


Figure 12 ESD Break in IC Chip (SEM)

Trace breaks and cracks in various layers can be discovered by opening the IC package and scanning with a SEM. Due to the extremely microscopic damage, we generally believe that this damage is caused by ESD, and this type of damage is also increasingly present in high-frequency modules. As a countermeasure to this increase in damage from ESD, we have not only established an in-house inspection system but are also perfecting inspection by external agencies, manufacturers, and others.

4.4 Sulfuration Analysis of Thick-Film Chip Resistors

Silver is commonly used for internal electrodes of thick-film chip resistors, but silver is easily corroded by atmospheric gases containing sulfur. Formation of silver sulfide (AgS) causes growth of AgS crystals with a needle like (whisker) form, depleting the electrode silver content and also causing short circuits. (Figure 13).

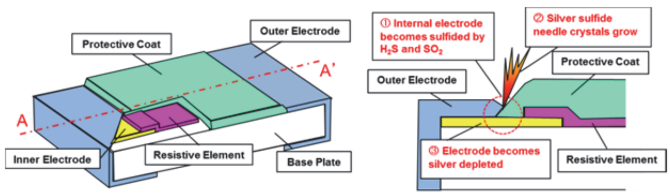


Figure 13 Cross-Section of Thick-Film Chip Resistor

Figure 14 shows silver whiskers growing on a thick film chip resistor.

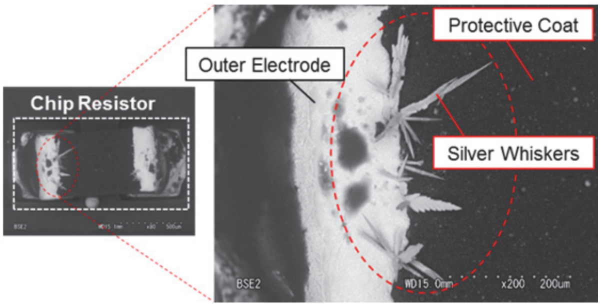


Figure 14 Silver Sulfide Crystal Formation (SEM)

An analysis using EDX (See Table 2 below) confirmed the presence of Ag and S in the parts and confirmed the existence of sulfide corrosion.

Table 2 Needle Crystal EDX Analysis Results [mass %]

	C	O	Si	S	Ag	Sn	Total
Contaminant	16.5	13.2	3.6	9.3	51.7	5.7	100.0

4.5 Accelerated Sulfuration Test Effect on Chip Resistors

The accelerated sulfuration test described in section 3.3 can be used to estimate the part's reliability from predetermined acceleration factors. Figure 15 shows examples for various types of chip resistor.

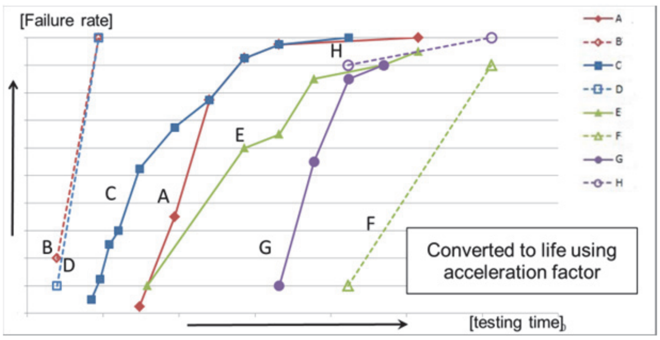


Figure15 Accelerated Sulfuration Resistance Test

We are also promoting the same evaluations for standard parts other than chip resistors with feed-back of the results to design departments.

4.6 Power Supply Unit (PSU) Corrosion Analysis Using EDX

Since the power supply unit in electrical equipment generates heat, ventilating cooling fans are used to disperse this heat. However, the ventilation air moved by the fans also pulls in dust and dirt, which can cause faults. Figure 16 shows an example of a failed PSU contaminated by dust and corrosion. The picture shows a large volume of accumulated dust between the choke coil and PC board. EDX analysis of this dust (Table 3) confirms the presence of high chlorine (Cl) levels.

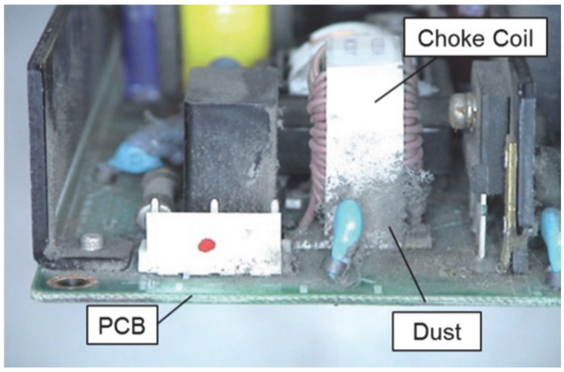


Figure 16 Internal View of PSU

Table 3 EDX Analysis Results of Coil Dust Contaminant [mass %]

	Na	Mg	Al	Si	S	Cl	K	Ca	Fe
Dust Contaminant	12.0	2.3	4.9	11.4	8.0	15.6	4.6	29.0	12.2

This corrosion is due to the presence of Cl in the dust and humidity in the ventilation air. Dusty and contaminated atmospheric air is common in NIEs where these faults are becoming increasingly common. As a countermeasure, specifying protective dust filters and PC board coatings at the design stage is effective, and parts manufacturers are being urged to use these countermeasures for their production as well.

4.7 Safety Verification of an AC Adapter DC Plug Insulation Plastics Using EDX

Insulation plastics include red phosphorus, which can cause insulation aging. When the insulation plastic of DC plugs of AC adapters ages, there is a high risk of shorting between the external and internal electrodes, which may cause a fire. Figure 17 shows the internal structure of these plugs.

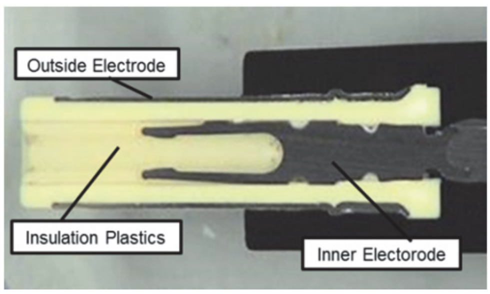


Figure 17 DC Plug Internal Structure

An EDX analysis can provide information about the presence of red phosphorus. The results of the following EDX analysis for red phosphorus (Table 4) in the insulation materials of a connector show that no phosphorus (P) is present.

Table 4 EDX Analysis Results of DC Plug Insulation Plastics [mass %]

	C	O	Si	Ca	Cu	Zn	Br	Sb	Total
Insulation	58.2	29.5	2.2	1.2	1.5	0.5	5.8	1.2	100.0

4.8 Internal Analysis of DC/DC Converter

Reflowing of solder during the Printed Circuit Board assembly process causes Ball Grid Array electrodes that are in contact with the internal structural parts to suffer failure risk if the pattern is crushed and shorted by the weight of the part.

This can be analyzed using an industrial X-ray CT scanner. Figure 18 shows a magnified view of the BGA electrode connections. To avoid high-risk faults, parts with structural stability are used, helping prevent failures.

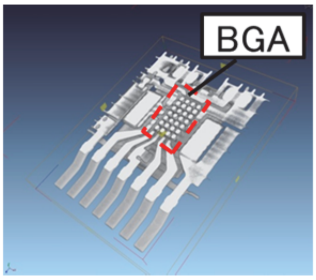


Figure 18 Magnified X-ray CT Scan

This issue has been observed in DC to DC converters, where it is important to use X-ray scanning equipment for internal inspections at the design stage.

4.9 High-Density Multi-pole Connector Contact Fault Analysis

Analysis of connector contact structures has the following problems:

- Inability to observe contact structure to confirm good or bad contact conditions from outside the connector
- When disconnecting the connector, the contact returns to the original state as a result of the spring action, preventing observation of a fault condition.

It has been shown that X-ray CT scanning equipment plays a vital role in revealing the causes of connection failure in high-density, multi-pole connectors. Figures 19 and 20 show CT scanner stereoscopic and cross-sectional images of contacts.

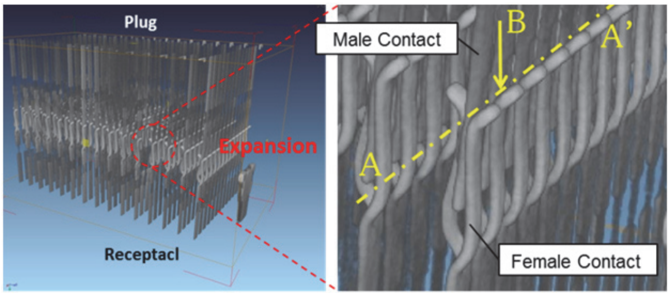


Figure 19 Connector (Fitting Condition) CT Scan Stereoscopic Image

These connectors use a stacked contact structure (vertical connections between horizontally arranged PC boards). The cause of poor connections is due to misalignment of the pins, thereby shorting when the male side of the connector is inserted into the female side.

The left side of Figure 19 shows a CT scanned stereoscopic image of the mating surfaces between the connector plug and socket, the right side is a magnified part of the image.

Figure 20 shows a cross-section CT scan of the contact conditions seen from the B side of the A-A' section in Figure 19.

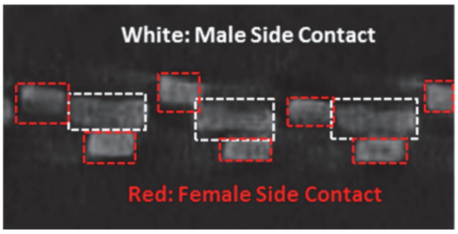


Figure 20 CT Scan of Contact Shorting

Figure 21 shows the diagnostic analysis of the connector, confirming abnormal mating surfaces between the male and female sides of the connector.

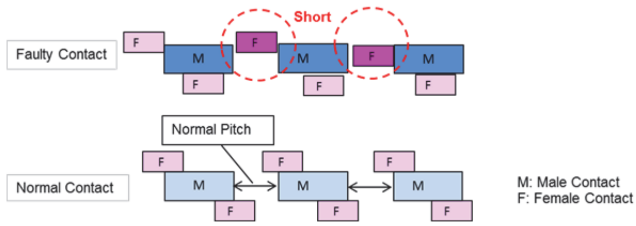


Figure 21 Faulty Contact Conditions

To prevent contact faults in high-pin-density multi-pole connectors, it is necessary to establish design and mounting rules to minimize deformation during insertion. In addition, it is also necessary to use multi-pole connectors with insulating structures between contacts. The X-ray CT scanner makes it possible to detect the condition of internal mating surfaces and it is very effective in finding mating conditions that can lead to failures.

5 Summary

The materials, structures and fabrication processes for increasingly small and diverse parts are undergoing a technological revolution, increasing the need for higher levels of analysis and inspection technologies. Consequently, understanding the fine detail of internal parts structures and developing high-reliability test methods are urgent problems to solve for manufacturers.

Anritsu's has made a large investment in equipment and expertise to ensure that parts and products are of the highest quality and reliability. Our inspection activities are focused on continuing to deliver materials and parts inspection service guides using our in-house Web services, as well as on building an easily searchable database of materials surveys that can be shared to implement pre-inspections before risks can occur.

We are continuing to build systems and processes covering a wide range of activities ensuring quality at every stage from design to production and ensuring highly reliable products.

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