Using Technical Cleanliness Assessments to Reduce Manufacturing Defects

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ABSTRACT

Modern vehicles contain a large amount of electronics and as this is a safety critical application a Zero Defect manufacturing policy needs to be implemented. Particulate contamination is the major cause of functional impairments in an electronics system. To achieve Zero Defects individual components such as PCBs are normally cleaned during and after manufacture and the level of cleanliness required for them to function properly is specified and tested. The German automotive industry has developed a methodology which can be used to test the Technical Cleanliness of component parts, such as PCBs VDA19 Part 1. Inspection of Technical Cleanliness – Particulate Contamination for functionally relevant automotive parts However in subsequent manufacturing steps there is a risk that the initially clean PCBs become recontaminated through transportation, storage and assembly. If the finished system cannot be cleaned after assembly, there is a chance for the contamination to remain in the end product and impair its function.

VDA19 Part 2 was developed to prevent the generation of critical particles of contamination at sensitive areas of manufacture, to remove unavoidable particles and to protect components and assembled systems against the entry of particles from the environment.

While there is guidance in VDA19 Part 2 as to areas to consider for mitigating the risk of contamination, an easy, quick method of assessing the level of Technical Cleanliness in real time is required. This would identify areas where the potential risk of particle generation is high and also document the effect of steps taken to reduce the risk of particle generation in each of the areas within the production process.

This paper will detail a Contamination Assessment Protocol, developed using Contact Cleaning technology that conforms to the guidelines in VDA19 Part 2 which will not only enable areas with the highest risk of contamination to be targeted for improvement measures but will also provide documentary evidence of the effect of any such improvements.

While a microscope may be required for detailed analysis of the results, instant feedback from the Particle Capture Sheet is clearly visible. After detailed analysis of each Particle Capture Sheet the results are assembled into a matrix which provides a map of the contamination within the production environment at a specific point in time. This can be helpful in identifying the initial source of particular types of particles as they move through the production area. This methodology is a quick easy way to assess levels of Technical Cleanliness using the results to implement improvement activities which reduce defects and improve productivity.

Key words: Technical Cleanliness, Elastomer Contact Cleaning, Reliability, Defects

INTRODUCTION

Today the use of electronics has become prevalent in all type of products with miniaturisation a trend in order to pack more functionality into smaller spaces. This trend has increased the risk of even small particles of contamination resulting in defects. The particles can be present on incoming materials such as PCBs, generated during the manufacturing process or present in the manufacturing environment. With particles currently responsible for around 75% of failures in populated PCBs it is essential that they are removed to increase reliability. Table 1 illustrates the number of particles of different sizes present in an assembled PCB.

Table 1. Particles in Assembled PCBs (4)

Empirical particle data from **assembled PCBs**[2] per 1000 cm² surface, based on particle class			
Particle size [µm]	Size classes	All particles	Metallic particles[1)]
50 ≤ x < 100	E	14500	1000
100 ≤ x < 150	F	2500	250
150 ≤ x < 200	G	800	90
200 ≤ x < 400	H	600	110
400 ≤ x < 600	I	70	17
600 ≤ x < 1000	J	20	13
1000 ≤ x	K	6	2

For safety critical applications such as in automotive, aerospace and medical products the philosophy of « Zero Defect, Zero Rework » is increasingly being specified. This results in a key focus on removing particles which generate defects during the manufacturing process.

TECHNICAL CLEANLINESS

Cleanliness is a rather arbitrary concept and difficult to quantify partly because contamination is so random. Also the level of cleanliness required depends on the specific application. This is because the size and type of particles depend on the design of the PCB. Technical Cleanliness is a methodology which uses standard tests to generate data which can be translated into a Specific Cleanliness Number. This number can then be used to specify to suppliers of materials, for example in PCBs, the level of cleanliness required. It can also be used to compare different production lines.

Components are defined as « Technically Clean » if they do not have any particles present which impair their function.

The methodology was developed by the German automotive industry who were concerned about failure in braking systems causes by particles within the hydraulic system. VDA19 Part 1 [1] is the standard they developed which defines the test methodology which is now used for all types of components. Subsequently VDA19 Part 2 [2)] was developed to consider particles in the manufacturing environment. More recently other organisations such as ISO [3] and ZVEI [4] have also developed standards and guidelines to Technical Cleanliness based around the VDA19. Technical Cleanliness establishes a uniform standard of cleanliness which can apply to different manufacturers and gives comparability. VDA19 Part 1 is focused on individual components. VDA19 Part 2 was developed for assembly processes. While other industry guidelines such as ISO 16232: Automotive Cleanliness Testing and ZVEI: Technical Cleanliness in Electronics and Electrical Engineering are also used, they are both based on the principles of VDA19. The approaches and methods detailed in VDA19 are so generic that they can be applied to the complete range of mechanical parts but need to be further defined specifically with regard to the requirements of electronic assemblies and PCBs which is why the ZVEI document was developed.

THE VDA19 PART 1 STANDARD METHODLOGY

There are three main stages in the testing procedures which form the basis of the Technical Cleanliness specification as shown in Figure 1, namely extraction, filtration and analysis.

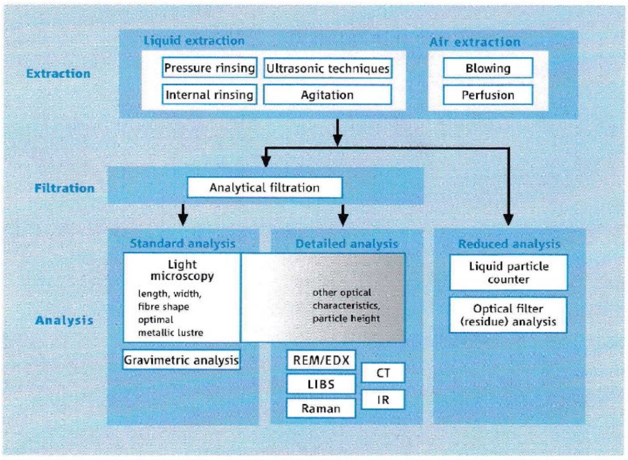


Figure 1. VDA Part 1 Methodology (4)

VDA19 Part 1 defines the steps required to develop a Technical Cleanliness Specification for a particular component. Firstly the relevant particle size must be established. This is chosen from assessment of the design or from previous defect analysis. While the example particle size in the document is 50 microns which is relevant to hydraulic systems, modern electronics will often require much smaller relevant particles. For testing, each sample component is placed in a chamber and all the particles are extracted using a pressure rinsing technique. The fluid used can vary dependent on the component but is often a solvent.

More recent editions of VDA 19 Part1 allow for the use of air to extract the particles from a component which cannot be exposed to moisture such as a PCB. The PCB is placed inside a sealed container. After the particles have been blown off the part by the air jets they are then then removed from the walls of the container using pressure rinsing.

Having gathered the particles in a liquid, the second step is to filter the liquid through a membrane which collects the particles contained in the liquid on its surface. The membrane is then oven dried to remove the fluid.

Analysis of the particles on the membrane counts and sizes the particles. Specific microscopes are available for the complete automatic analysis of the membrane. Gravimetry can also be used for analysis but it is more relevant to large metal component than for PCBs where the weight of particles is very small.

The final stage is completing a range of calculations which result in a Technical Cleanliness Specification for the specific part.

ISSUES WITH THE STANDARD METHODOLOGY

While the VDA19 Part 1 methodology is excellent at providing comparative values of Technical Cleanliness, when it comes to the reliability and consistency of particle removal there are some issues.

Firstly VDA19 Part 1 is based on a sampling technique and as particle contamination is a random occurrence it may be that although the samples tested have an acceptable technical cleanliness level the rest of the components may not.

Secondly while the samples have the particles of contamination removed, the particles are is still present on the rest of the batch of parts which does not help the aim of Zero defects.

Thirdly the testing process takes significant time to achieve results. Also with the need for specialised equipment and skilled staff testing is often conducted at off-site laboratories. Even when the testing is done in the production facility the use of the pressure rinsing technique it takes a significant time. This makes it unsuitable for high volume production.

Lastly the testing methodology involves many variables making the results less accurate than ideally required.

What is needed is a test method which uses the VDA19 approach but can be incorporated into the production line to give the specific cleanliness number in real time while removing all the particles of contamination from every part.

ALTERNATIVE APPROACH

The key to improving the VDA methodology is developing an alternative extraction technique which can be applied to every part in a manufacturing run. It should also be able to provide an cleanliness assessment in real time to suit high volume production lines.

There are many established techniques for particle removal already in use in production lines in the electronics industry today. Working with a Japanese company, the particle removal efficiency of the various methods was assessed with particular focus on removal of different sizes of particles. As can be seen from Figure 2 the most efficient method of removal was achieved using specially formulated elastomer rollers and this result held true over all particle sizes down to the nanometer range.

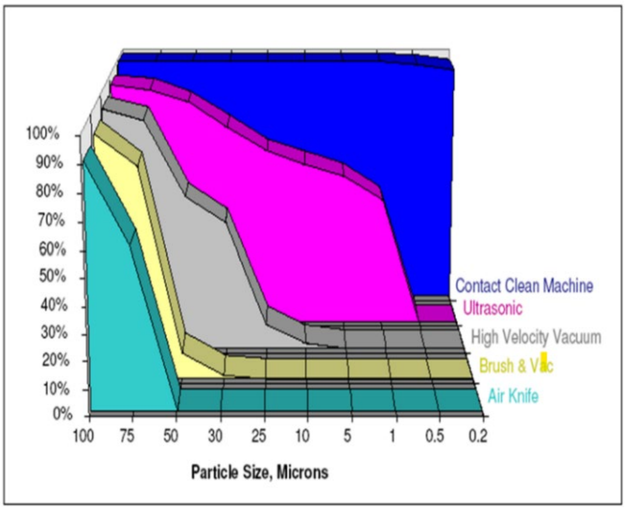


Figure 2. Efficiency of Different Particle Removal Methods

These results demonstrate that specially formulated elastomer roller cleaning known as Contact Cleaning gives better particle removal than other common cleaning methods. As the electronics become more densely packed, smaller particles can significantly impact reliability and so the comparative effectiveness of Elastomer Contact Cleaning, as shown in Figure 2, increases as particles get smaller making it ideal for improving reliability in High Density Interconnection boards.

This particle removal technique, which is widely used for cleaning in SMT assembly lines, does not currently conform to VDA19 Part1 and was chosen as the foundation of a modified extraction methodology which requires to be qualified according the VDA19 Part 1 criteria. This is to ensure that the maximum number of particles possible are removed from the test component.

ELASTOMER ROLLER EXTRACTION

To perform the VDA19 Part 1 extraction qualification tests on elastomer rollers an independent accredited laboratory, which specialises in particle testing and in VDA19 Part 1 testing in particular was chosen.

To conduct this test a PCB was heavily contaminated with calibrated particles which were black in colour to provide a contrast for the optical microscope. Increasing contrast improves the accuracy of the particle count. The test roller was then run over the PCB and the particles rinsed off the elastomer rollers using a standard VDA19 Part 1 extraction pressure rinsing procedure. The particles on the filter were then counted and sized using automated microscopy as well as gravimetry. This procedure was repeated on the same PCB six times using the same elastomer roll without recontaminating the PCB. This follows the qualification procedure.

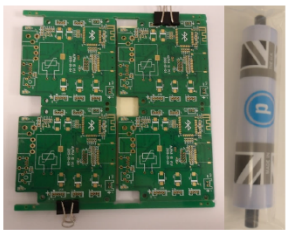
To meet the qualifying conditions the count of the extracted particles from the elastomer roller must continuously decrease. By the sixth analysis, at the latest, the particle count must be less than or equal to 10% of the sum of all the previous analysis. These are the conditions for the declining extraction curve necessary for extraction qualification.

The documents recording the test conditions for the standard extraction technique used for removing the particles from the elastomer roller are shown in Figures 3 and 4.

As can be seen there are a large number of variables which have to be documented and if the extraction technique does not give a declining curve the tests must be repeated with the variables changed until the extraction technique is qualified. This then is defined as the technique to be used for all subsequent testing of this specific part.

Test 1(A-F)	
Component Description/Identification on the part	
PD12692IA 6 tests on 1 roller used on 1 contaminated PCB	
Number of tests per part	1
Number of parts per test	1

Component image



PTL Component Identification			
SID	44503		
Supplied Surface		Area per part cm^2	
Gauss meter result Before/after demag		0.2 / xxxx	
Demagnitisation		No	
Filter occupancy (%)		13.84/0.75/0.06/ 0.04/0.02/0.01	

Component Condition
Component arrived in a sealed bag Component arrived in good condition

Figure 3. Test Component Description

Test Conditions						
Membrane Type	Mesh 5	*μm*	Rinse Fluid Type	ISO Paraffin (<5mm2/s)	15-35	°C
Rinse Pressure	0.5 ±0.1	*barg*	Extraction Method	Pressure rinse (whole part external)		
Test Duration	n/a	*min:s*	Flow Rate	n/a	*l/min*	
Counting Method	Leica microscope Transmitted		Fibre definition	Fibre length to width ratio 20:1, <= 50 μm width		
Fibre -Feretmax length-the greatest possible perpendicular distance measured between two parallel lines						
Beaker Collection*	Yes	Filtration Equipment		Yes	Testing as received	
*13x9cm (HxD)						
Gravimetric		Yes	Rinse Fluid Volume*	6x1000** -0+20%	*ml*	
*Record volume		**1000ml cabinet rinse / 200ml beaker funnel rinse / 200ml part rinse				
Nozzle Type	2	*mm*	Validated extraction procedure >90%		No	

Figure 4. Test Conditions

Additional information regarding the testing process is contained in Figure 5.

All tests were carried out by the same technician to ensure that the test procedure was as consistent as possible.

Additional Testing Information

Preparation stage

1 - The gauss of the parts were recorded, where possible if the value was over 5 gauss the parts were demagnetised and then measured/recorded again.

2 - The test equipment cleaned in preparation for the blank analysis.

Blank 1 stage

4 - A blank analysis was performed by rinsing the test equipment and filtered through a blank membrane using 1000ml of rinse fluid.

5 - The blank membrane was dried and counted, once the blank result passed the requirements the test was ready to proceed.

Testing stage

6 - The parts were held above/ placed on soft testing strips in the test equipment.

7 - The parts were rinsed with T1A-6 6x1000ml, T2-7, T8-9 of fluid. The parts were removed and the test equipment rinsed with 200ml/1000ml to ensure all of the particles have been collected (Beaker/funnel rinse).

8 - The membrane removed, dried and counted.

9 - The parts were drained and dried in an oven at 60 degrees where possible, placed in original packaging.

Figure 5. Additional Test Information

The results of the particle counts from the elastomer roller qualification tests after each iteration are shown in Table 2.

Table 2. Particle Counts from the Six Tests

Particle and Fibre size *µm*	1A	1B	1C	1D	1E	1F
5 - 15	118510	59465	5853	3552	1267	661
15 - 25	78551	31231	2076	1231	465	266
25 - 50	101972	8552	339	275	141	53
50 - 100	58970	366	25	30	25	8
100 - 150	25899	20	5	5	2	2
150 - 200	6513	13	6	3	3	2
200 - 400	840	10	9	9	1	1
400 - 600	6	3	1	1	4	2
600 - 1000	2	2	2	0	1	1
>= 1000	1	0	3	0	1	1
% Extraction >5*µm*	100	20.3	1.7	1.0	0.4	0.2

The resulting data show a declining curve as required by VDA19 qualification and also show that the condition for qualification is met after only two iterations of roller testing.

Gravimetric testing was also used to validate the declining curve and the results of this testing can be seen in Table 3.

Table 3. Gravimetric Results from Six Tests

Test	Initial filter mass *g*	Final filter mass *g*	Total particulate mass *mg*
T1A	0.11315	0.1401	27.0
T1B	0.11326	0.11561	2.4
T1C	0.11311	0.11361	0.5
T1D	0.1133	0.11379	0.5
T1E	0.1128	0.11321	0.4
T1F	0.11307	0.11342	0.4

Some images and description of the particles found on the filter paper during microscopy can be seen in Figure 6.

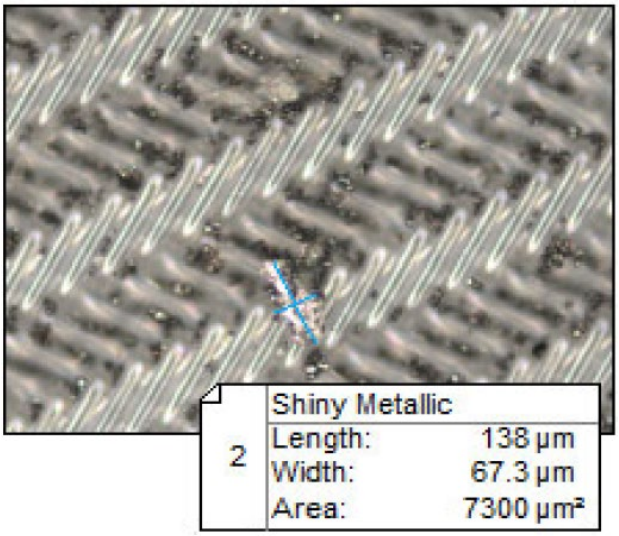


Figure 6.A Filter from Iteration 1

Photograph, 6A, shows the filter membrane after the first iteration of testing. The filter paper is very contaminated with the black particles used on the PCB and also shows a metallic particle.

Photograph, 6B, is from the second test showing just a few black particles and another metallic particle.

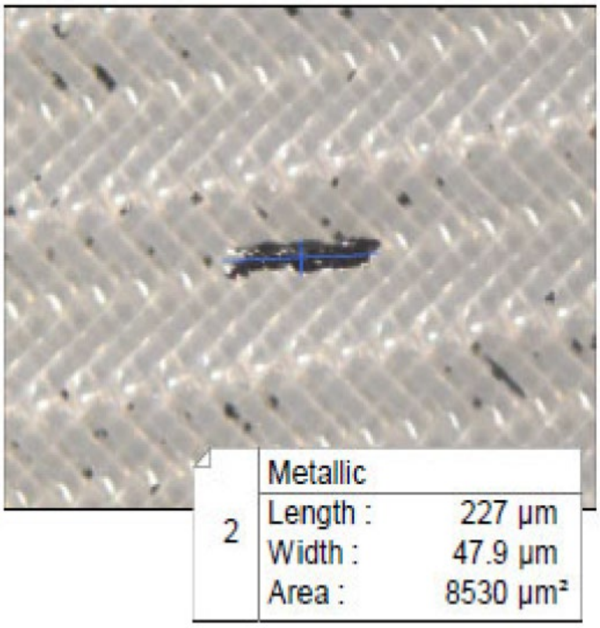


Figure 6B. Filter membrane from second test

The final photograph, 6C, from test three shows only two black particles and a green fibre which may be from the solder resist.

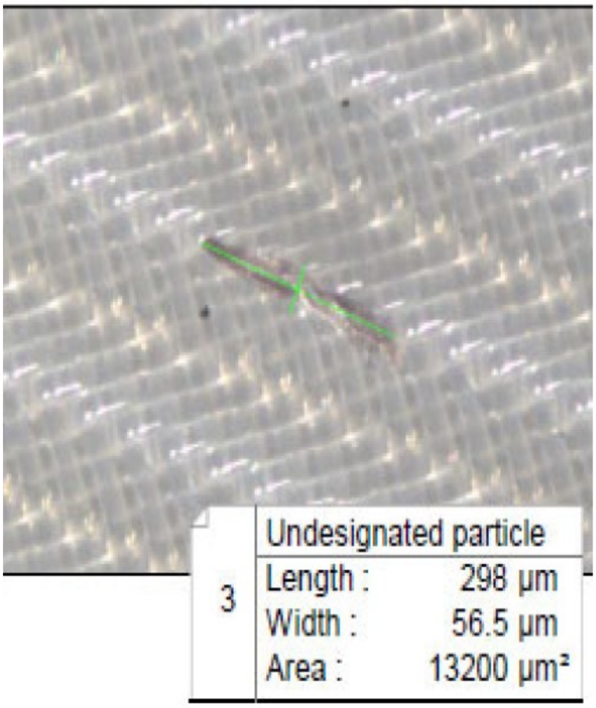


Figure 6C. Filter membrane from third test

The specially formulated elastomer roller technology has easily passed the VDA19 Part 1 Extraction Qualification test.

ALTERNATIVE TO FILTRATION

When using liquid extraction techniques the particles are collected on a white filter paper for analysis. The elastomer roller extraction technique requires the particles to be collected on a white adhesive paper for analysis. This is achieved by rolling the elastomer roller with the extracted particles onto the adhesive surface which then captures all the particles from the roller. The adhesive rolls are presheeted and because each sheet can be easily removed from the roll it can be used as the equivalent of the VDA19 Part 1 filtration method and the can be also used for analysis using VDA19 Part1 techniques. The final photograph, 6C, from test three shows only two black particles and a green fibre which may be from the solder resist.

This combination of elastomer roller and adhesive eliminates the need for considerable quantities of solvent making the test process more sustainable. It avoids the risk of an explosion hazard as well as being safer for the laboratory technicians by eliminating vapour exposure. It also avoids the need for oven drying and allows a significant reduction in the time needed to achieve testing results.

ANALYSIS

The analysis techniques for counting and identifying the particles on the adhesive paper are identical to those used on the filter membrane for liquid extraction in the VDA Part 1 methodology.

USE IN THE PCB ASSEMBLY LINE

While PCB manufacturers may use VDA 19 Methodology and Contact Cleaning during the production of the PCBs, the packaging and transport of the boards between the PCB production facility and the assembly facility can generate particles either from the packaging materials or through wearing of the boards as they rub against each other during transportation. Unwrapping stacks of boards from plastic film can also generate static electricity which attracts particles from the air to the surface of the boards. This means that the PCBs require to be cleaned again at the start of the SMT assembly process.

This qualified elastomer extraction roller system with its proven particle removal efficiency can be integrated into existing cleaning equipment on SMT assembly lines as shown in Figure 7.

It can remove particles from bare PCBs at the start of the line before solder paste print which is the area where particles cause most defects. It provides instant visual feedback on the level of particulate on the Particle Capture Sheets of adhesive while enabling the calculation protocols of VDA19 Part 1 to be used to determine the Technical Cleanliness Level of the PCB in real time. The particle Capture Sheets can easily be removed from the pre-sheeted roll for analysis. By overlaminating the sheets they can be stored as part of a quality archive.

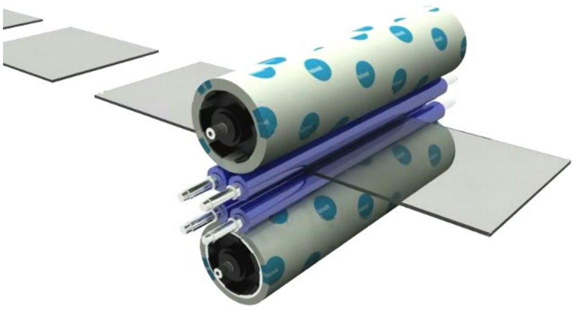


Figure 7. Qualified Elastomer Extraction cleaner in line

In contrast to the VDA19 Part 1 methodology, the particle, including small ones are removed from every PCB immediately before solder paste print which is the process step where the most defects are caused by particles This greatly increases reliability in high volume manufacture of PCBs as the particle extraction is fully integrated into the assembly process.

CONTAMINATION ASSESSMENT PROTOCOL

VDA19 Part 2 focuses on particles in the process environment which may affect the PCB at any stage of the assembly process. While many Surface Mount Assembly lines are not situated in a clean room environment, regular assessment of the environment level of particles is crucial to the reliability of the final product.

Currently the standard method for evaluating particles in the environment is using a Particle Trap or sedimentation surface. This involves a glass Petri dish containing an adhesive coated disc. This dish is placed on a horizontal surface before being uncovered and left for a specific period of time. The disc is then microscopically analysed to determine the particle size and count. This technique is really only relevant for airborne particles which are a small percentage of those particles causing defects.

The use of qualified elastomer extraction rollers opens up a new way of assessing particles either on the equipment or in the environment. The rollers can be used on any type of dry surface. A Contamination Assessment Protocol has been developed to allow an audit of contamination throughout the process environment. This uses the elastomer extraction roller in a hand unit to roll over a defined sample area of the selected surface capturing any particles present. The samples should be taken from many different areas throughout the process area, from the tops of cabinets to capture airborne particles to the floors under equipment where heavier particles are found. Conveyors over which the PCB will run should also be sampled.

For each sample the particles are then transferred from the elastomer extraction roller to a Particle Capture Sheet which is overlaminated and annotated with date and location of the sample before going for analysis. The Particle Capture Sheet also provides instant visual indication of the contamination present as shown in Figure 8 and 9. Figure 8 shows a sample taken from the top of a cabinet while Figure 9 shows one from under a conveyor.

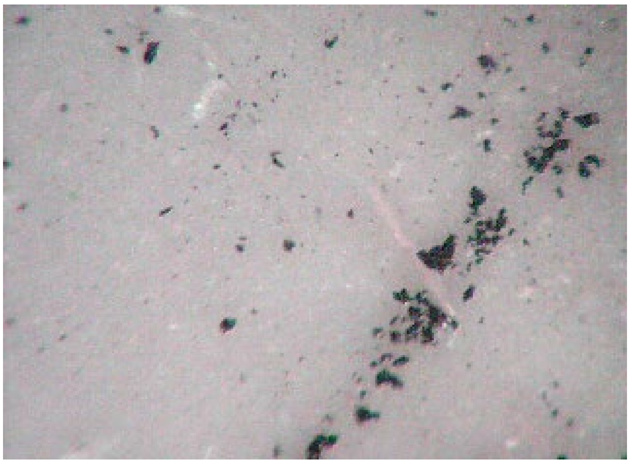


Figure 8. Particle Capture Sheet from top of cabinet

Figure 9. Particle Capture Sheet from under conveyor

The particle Capture Sheet can be analysed using automated microscopy to provide a database of particle count including size. This database is used to calculate the Technical Cleanliness Numbers.

One way of capturing the data is in a matrix as shown in Table 4 and in larger format in Appendix A where the count from every sampling station is contained in a single document.

Table 4. Particle Count Matrix

	Operator				Process						Resins									
	Clothes Fibres	Threads	Hair	Clear Fibres	Epoxy Resin	Epoxy Glass	Copper	Dry film	Solder Mask	Red Emulsion	Clear	White	Yellow	Red	Blue	Green	Black	Grey	Amber	Orange
Artmaster (Main)	3	3	2		1	1	2				1	3	1	3	3	3	1	1	3	1
Artmaster (Lamination)	4	1	2				2				1	2	2	3	2	1	2		1	2
Artmaster (Darkroom)	3	1	3	2			1			1	1	2	3	1		2	2	2	2	2
Inner Layer Print	4	2	2	1		2	3	2	1		2	2	1	2	1	1	2	3	1	1
Inner Layer A.O.I.	4'	2	2	1	1	2	4	2	2			1	1	1	1	1	2	1	1	1
Stack Up	3	1	1	1	4	3	1					1		1	1		1	1	2	1
Hard Board Print Dry Film Lamination	4	1	2	2	1	1	3	3			1	2	1	2	1	1	1	1	1	2
Hard Board Print Manual Exposure	4'	1	2	1	2	2	4'	2			1	2	2	2	1		1	2	1	3
Hard Board Print Auto Exposure	4		2	1	1	1	3	3			2	2	1	2	2	1	2	1	1	1
Solder Mask Electrostatic Spray	3	1	2	1		1	2		3		1	2	1	1	2	1	2	1	1	1
Solder Mask Auto Exposure Lines	4	1	2	1	1		3		4		2		2	2	2	1	2	2	2	1
Solder Mask Curtain Coating	4	1	2	1		1	2	1	4		2	2	1	1	1	1	2	1	1	1

	Miscellaneous																			
	Plastic Film	Metal	Brass	Wallboard	Rust	Foam	Rubber	Non woven fabric	Cellulose	Glass	Vegetable Matter	Stones	White Waxy Sub	Black Debris	Brown Debris	Foam Mat	Coated fibres	Spheres	Skin	Insect
Artmaster (Main)	1	3	1	1		1	2		3	1	1	2	3	3	1	2	1	1		
Artmaster (Lamination)	1	2		2	1		2		3	2	1	1	2	2			1			
Artmaster (Darkroom)		3	1		1		1		2		2		2	3	2	2		1		
Inner Layer Print	2	4	1	1	1		2	1	4	2	1	2	2	2	1	1	1	1	1	
Inner Layer A.O.I.		3		1			2	1	2	1	1	1	1	2		2		1	1	1
Stack Up	1	1	1		1			1	1			1	1	1	1				1	
Hard Board Print Dry Film Lamination	1	3	1	1	1		2	1		1		1	1	3	2				1	
Hard Board Print Manual Exposure	2	3	3				4		1	1		1	1	3					1	
Hard Board Print Auto Exposure	1	3	1		1		2		2	1	1	1	1	3	1	1	1	1	1	
Solder Mask Electrostatic Spray		2			1		1		3	1	1	1	2	2	1	1		2	2	
Solder Mask Auto Exposure Lines		4	1		1	1	2		3	2	1	1	2	3	1	1	1	1	1	1
Solder Mask Curtain Coating	1	2		1	1		3		1	1		1	1	2	2	1	1	1	1	

KEY: 76 - 100 = 4; 51 - 75 = 3; 26 - 50 = 2; 1 - 25 = 1

This matrix can be used to trace the source of a particular type of contamination and to highlight process areas which pose a potential risk to the product. A key use for the matrix in to document the results of improvement activities by comparing the matrices before and after each activity and counting the particle reductions.

The benefits of this type of elastomer extraction roller cleaning in PCBA manufacturing is best demonstrated by figures shared by a European assembly company which show the significant reduction in defects when an elastomer extraction roller cleaner was installed. See Figure 10

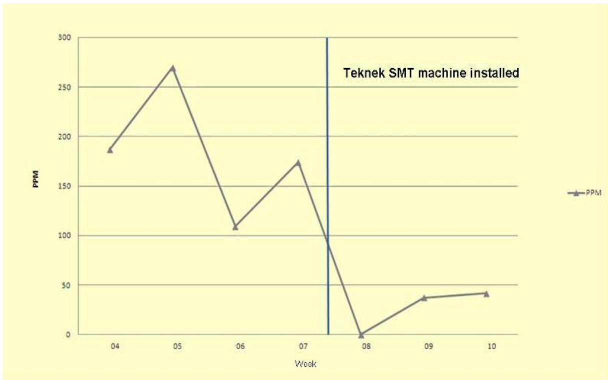


Figure 10. Defect Reduction

CONCLUSIONS

By utilising the proven principles and methodology of VDA19 Part 1, Qualified Roller Extraction Cleaning can overcome many of the downsides associated with its use in high volume SMT assembly lines.

1 It can remove particles from every PCB passing down the assembly line reducing defects.
2 It provides visual results in real time
3 It significantly shortens the time to get a Technical Cleanliness number

4 It does not require solvent, complex equipment or highly trained technicians
5 It enables a Contamination Assessment Protocol in line with VDA19 Part2
6 Particle Capture Sheets can easily be archived for future comparison

REFERENCES

[1] Verband der Automobilindustrie, Quality Management in the Automotive Industry, Part 1, Inspection of Technical Cleanliness

[2] Verband der Automobilindustrie, Quality Management in the Automotive Industry, Part 2. Technical Cleanliness in assembly

[3] ISO16232 : Automotive Cleanliness Testing

[4] ZVEI German Electrical and Electronic Manufacturers Association, Electronic Components and Systems Division, Technical Cleanliness in Electrical Engineering

APPENDIX A

	Operator				Process						Resins										Miscellaneous																			
	Clothes Fibres	Threads	Hair	Clear Fibres	Epoxy Resin	Epoxy Glass	Copper	Dry film	Solder Mask	Red Emulsion	Clear	White	Yellow	Red	Blue	Green	Black	Grey	Amber	Orange	Plastic Film	Metal	Brass	Wallboard	Rust	Foam	Rubber	Non woven fabric	Cellulose	Glass	Vegetable Matter	Stones	White Waxy Sub	Black Debris	Brown Debris	Foam Mat	Coated fibres	Spheres	Skin	Insect
Artmaster (Main)	3	3	2		1	1	2				1	3	1	3	3	3	1	1	3	1	1	3	1	1		1	2		3	1	1	2	3	3	1	2	1	1		
Artmaster (Lamination)	4	1	2				2				1	2	2	3	2	1	2		1	2	1	2		2	1		2		3	2	1	1	2	2			1			
Artmaster (Darkroom)	3	1	3	2			1			1	1	2	3	1		2	2	2	2	2		3	1		1		1		2		2		2	3	2	2		1		
Inner Layer Print	4	2	2	1		2	3	2	1		2	2	1	2	1	1	2	3	1	1	2	4	1	1	1		2	1	4	2	1	2	2	2	1	1	1	1	1	
Inner Layer A.O.I.	4*	2	2	1	1	2	4	2	2			1	1	1	1	1	2	1	1	1		3		1			2	1	2	1	1	1	1	2		2		1	1	1
Stack Up	3	1	1	1	4	3	1					1		1	1		1	1	2	1	1	1	1		1			1	1			1	1	1	1				1	
Hard Board Print Dry Film Lamination	4	1	2	2	1	1	3	3			1	2	1	2	1	1	1	1	1	2	1	3	1	1	1		2	1		1		1	1	3	2				1	
Hard Board Print Manual Exposure	4*	1	2	1	2	2	4*	2			1	2	2	2	1		1	2	1	3	2	3	3				4		1	1		1	1	3					1	
Hard Board Print Auto Exposure	4		2	1	1	1	3	3			2	2	1	2	2	1	2	1	1	1	1	3	1		1		2		2	1	1	1	1	3	1	1	1	1	1	
Solder Mask Electrostatic Spray	3	1	2	1		1	2		3		1	2	1	1	2	1	2	1	1	1		2			1		1		3	1	1	1	2	2	1	1		2	2	
Solder Mask Auto Exposure Lines	4	1	2	1	1		3		4		2		2	2	2	1	2	2	2	1		4	1		1	1	2		3	2	1	1	2	3	1	1	1	1	1	1
Solder Mask Curtain Coating	4	1	2	1		1	2	1	4		2	2	1	1	1	1	2	1	1	1	1	2		1	1		3		1	1		1	1	2	2	1	1	1	1	
KEY		76 - 100		4			51 - 75		3			26 - 50		2			1 - 25		1		..																			