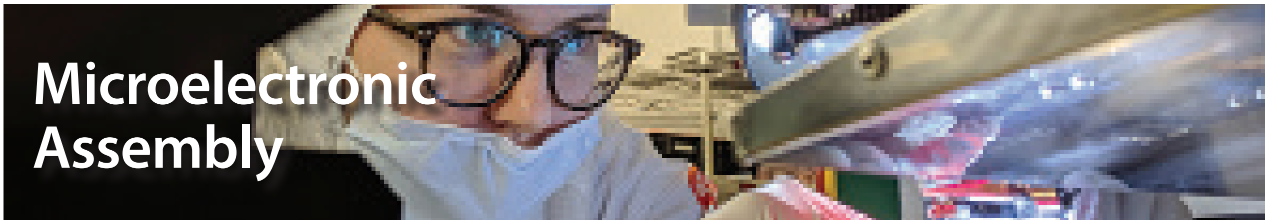

SILICON Heartland OH SMART MICROSYSTEMS

Considerations for Developing Innovative Products with Microelectronic Assemblies

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ENTERING THE MARKET WITH A NEW, innovative product can be a particularly daunting task. Even the most seasoned product development teams mistakenly rely on a traditional serial approach. For fast-paced and demanding markets, this traditional product development cycle will not meet the market needs in terms of cost and timing. To encourage engineering that begins with the end in mind, Test Early Test Often and Concurrent Engineering are two strategies which can meet market demands. These product development strategies create quicker learning and shorter design cycles. By implementing these two strategies, product development teams can lower overall development time and cost.

The traditional product development cycle (PDC) often leads to projects running over budget and behind schedule. Traditional PDCs begin with several design iterations which include thorough design reviews at each stage. Each iteration is typically followed by models and simulations, which in turn are followed by more design iterations. These steps take place over an extended period of time, only after which the design is declared complete and subsequently "frozen". Samples constructed using the frozen design are tested, which results in the discovery of preventable flaws which then must be addressed with yet another design iteration.

As the traditional PDC continues to iterate, the clock continues to tick, and the budget continues to deplete – meanwhile, the manufacturing process has yet to be considered. Most design teams reach the end of the design phase with enough fixes to get a functional product, but over budget, out of time, and without addressing manufacturability. This type of PDC is costly and the unnecessary serial iterations allow time for competitors to gain market entry first. More disadvantageous yet, without time left to establish the process portion of development, traditional PDCs can lead to manufacturing a product that is not sustainable.

The Test Early Test Often approach to product development addresses the flaws of the traditional PDC. This strategy shortens the overall PDC by employing targeted testing early in the development process. The Test Early Test Often approach uncovers weaknesses in designs by testing fundamental design and process assumptions before too much value is added to the part. In this strategy, requirements for new science are highlighted, potential issues are addressed before they become integrated into the process, and the overall cycle of iterative changes is shortened. The Test Early Test Often strategy relies on low-cost modular samples to perform testing instead of relying on assembled prototypes. To test wire bonds, for example, a shake test on a costly end-of-design prototype sample would be performed in the traditional PDC. A low-cost modular sample, however, could provide valuable early data. This modular sample, such as a 50x50mm aluminum plate populated with 1 mil aluminum wedge bonds of a defined loop height and geometry, can be produced in a few days and subjected to a one hour 10g sinusoidal vibration profile. Results (as shown in the SEM images in Figure 1) can be analyzed in multiple ways, including optical and acoustic microscopy, X-Ray, and SEM. The whole test can be completed in less than a week with the learning incorporated into the early stages of the design and process engineering.

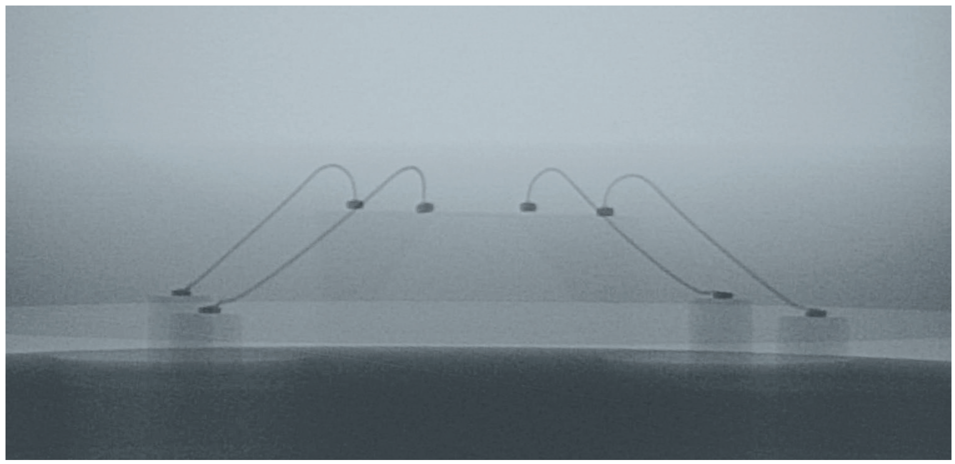


Figure 1. Microelectronic Pressure Sensor Assembly.

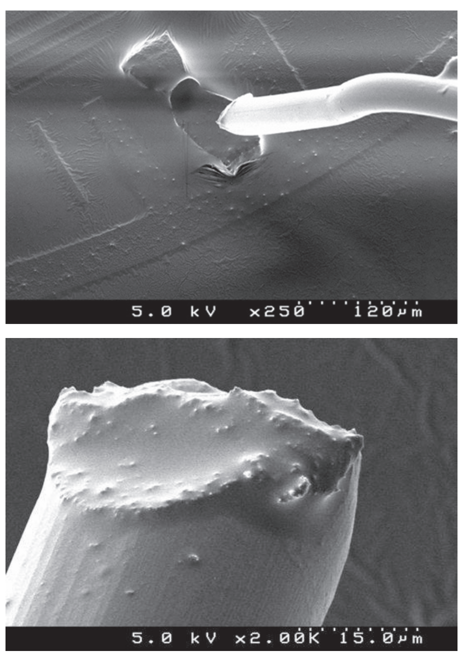
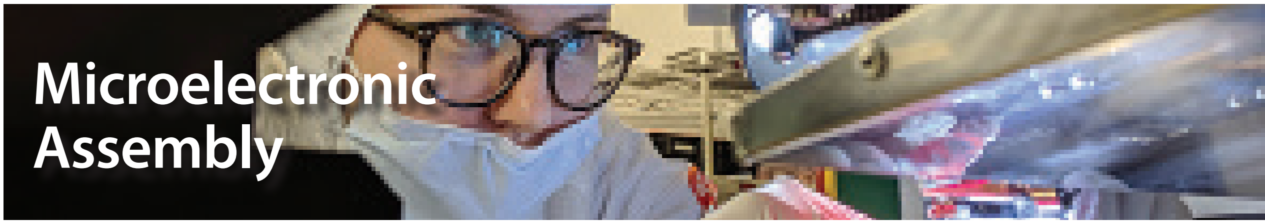


Figure 2. Scanning Electron Microscope (SEM) images of Al wire bond after test.

The Test Early Test Often approach also takes advantage of rapid prototyping to implement targeted tests to create quicker learn-



ing. For example, assemblies can be made from high-temperature SLA materials to enable -40°C to 125°C thermal cycling. This allows for early understanding of possible CTE mismatch issues. If this test was dependent on the availability of injection-molded parts – as would be necessary in the traditional PDC – the learning gained would not be available in the early design iterations.

Another strategy to address the pitfalls of the traditional PDC is the Concurrent Engineering approach to product development. Concurrent Engineering promotes manufacturable design and reduces over-all product development cost by creating synergies between design and process engineering groups. By beginning with the end in mind, this strategy encourages the design engineer to consider the process and the process engineer to consider the design. For example, Concurrent Engineering encourages a scaleable tooling strategy that can grow to last the life of the program. If production volumes are going to increase, tooling can be designed flexible enough to integrate a conveyor feed later in the program. Lower capital investment is needed to implement a conveyorized solution since the tooling does not need to be redesigned.

When the design and process development is conducted concurrently, and early testing is performed, learning is quicker and the design cycles become much shorter. Implementation of Concurrent Engineering hand-in-hand with the Test Early Test Often strategy adds real, measurable value. These combined engineering strategies significantly lower overall development time and cost.

In the world of new product development, failure analysis is another tool that can reduce costs and accelerate time to market. Failure analysis can be used to achieve a better understanding of the behavior of a microelectronic assembly after being stressed by the conditions from its application environment. In a thoughtful design, the environmental conditions in which a product is intended to function need to be considered carefully. Once these conditions have been determined, a life test profile is defined in order to simulate the environmental conditions in which the product will need to survive. When the life test profile is completed, a functional test is performed to evaluate whether the product is still operating according to customer specifications. The next step is to perform destructive and/ or non-destructive analysis of the product to identify its strengths and weaknesses. Analysis should always be conducted regardless of whether or not there is a confirmed failure. Finally, the lessons learned from the analysis must be fed back to the product design team to improve the product, lower the cost, or both.

The environmental conditions for a microelectronic assembly are requirements driven by the customer. An automotive application for example, will have a different set of requirements than a part with an aerospace application. The end user or customer typically has a good understanding of how the part will be used and the environment in which it must survive. High temperature endurance, low temperature endurance, and UV exposure are examples of tests that are used to replicate common environmental conditions.

A life test profile is developed by the customer in an effort to simulate the environmental conditions to which the part will be subjected during use. (see Figure 3)These tests, or series of tests, are intended to accelerate the life exposure of the product and can sometimes be harsher than the actual operating conditions

Product Validation Test Plan

Section	Test	Results Pass	Fail	Dur. Days*	Pre Function	Post function	Visual Insp.	# of Parts	Weeks 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Test	**Functional tests**																									
1	Function test (Leak, Characterize, Insulation Resistance)			1	Yes	Yes	No																			
2	Function test			1	Yes	Yes	No																			
3	Characterization			1	Yes	Yes	No																			
4	Presure cycle test			1	Yes	Yes	No																			
	Environmental test requirements for product verification																									
5	Humidity Cycling			30	Yes	Yes	No																			
6	Salt spray fog (144h @ DIN 50 021 SS)			8	Yes	Yes	Yes																			
7	Heat Soak			91	Yes	Yes	No																			
8	Cold Soak			91	Yes	Yes	Yes																			
	Thermal Loading and Endurance																									
9	Thermal shock test (200 cycles)			10	Yes	Yes	No				SEQUENTIAL TEST															
10	Extended Thermal Shock (1000 cycles)			50	Yes	Yes	No				SEQUENTIAL TEST															
11	Endurance test			40	Yes	Yes	No																			
12	Stepped temperature test			2	Yes	Yes	No				SEQUENTIAL TEST															
13	Ice water shock test (100 cycles)			4	Yes	Yes	Yes				SEQUENTIAL TEST															
	Misc																									
14	UV testing			5	No	No	Yes																			
15	HAST testing			1	No	No	Yes																			

Figure 3. Example of Life Test Profile.

of the product. For example, air to air thermal shock exposure is a commonly performed test that can stress a mechanical sensor package to premature failure. The life test profile includes tests that represent both actual environmental conditions and accelerated environmental conditions in order to create learning about failures, potential failures, or both.

Functional tests can vary widely and are driven by the operating requirements of the product. This can include visual inspection, measurements taken after the life test profile, and/or measurements taken during certain tests. In the case of a MEMS pressure sensor, the functional test will typically include current draw, output as a response to applied pressure (characteristic curve), and a leak test. In many cases, monitoring the sensor output function throughout testing is required to determine the exact moment of failure—if and when it occurs. There is also typically a mechanical package inspection requirement to determine if any physical damage to the package occurred as a result of the life test profile.

If a functional failure does occur from the life test profile, analysis should be performed to determine the root cause of the failure. Non-destructive analysis techniques include optical microscope inspection, 3D X-ray, and acoustic microscopy. Destructive disassembly follows which could include shear/pull testing, cross sections, scanning electron microscopy (SEM), optical microscopy, and elemental surface analysis such as emission dispersive spectroscopy (EDS). If all of the parts on test survive the entire life test profile without a failure, a complete post-test analysis should still be conducted in order to determine if there are any parts near failure or areas for improvement. (see Figure 4) Additionally, it is recommended that non-destructive analysis techniques should be used to capture images of parts before the life test profile, so that there is a base line for comparison once testing is complete. In some instances, design and process improvements can be identified by uncovering potential weaknesses after the life test profile, even without a demonstrated failure.

In this stage of the new product develop- review is in order. It is important to use all collected data to drive design and process improvements. This aligns with proven new product development strategies such as: test early, test often and concurrent engineering. The idea is to create early learning using failure analysis results in order to implement improvements before freezing the product design. The results of this "lessons learned" review drive action in the form of a Risk Analysis, PFMEA, DFMEA, other six sigma techniques and quality methods. Failure analysis is an effective tool for the development of microelectronic assemblies for new products. It can be used to understand the behavior of a part in the given application environment. A life test profile evaluates the effects of the environmental conditions against the design objectives and a developed manufacturing process. Functional testing and non-destructive/destructive analysis provides the lessons learned where immediate inputs to the new product development cycle can reduce development costs and time to market.

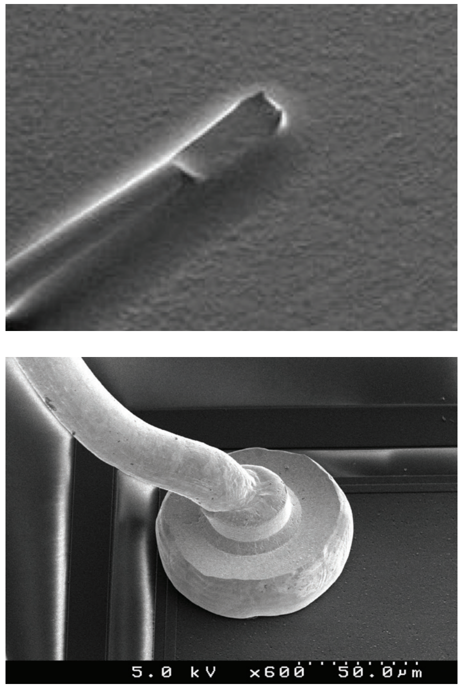
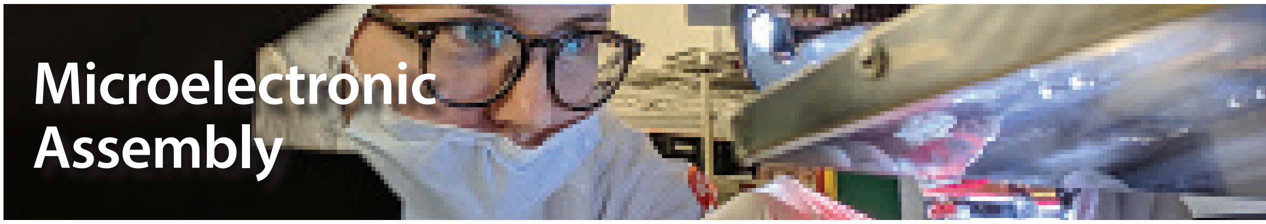


Figure 4. Wire bonds that survived life test profile.

In theory, if an organization executed on a robust design and a properly developed assembly process, the "big day" ought to be a flawless product launch. If this is the case, then why are so many product launches flawed? Experience shows that, in some part, all new product launches have some degree of difficulty that needs to be overcome. That is why it is critical to do everything possible to make it successful. Whether launching a product or a subassembly for a product, the challenges can be equally as demanding. The key to a well-executed product launch is a thoughtful, well-documented plan that contains several crucial elements. A 3-year product volume ramp plan, a capacity ramp plan, FMEA, PFMEA, risk analysis, NPD readiness reviews, control plans, and engineering process reviews are just some of the many tools that are used by ISO organizations in preparation for product launch.

Many times the question is asked, "When is it a good time to start planning for product launch"? It is always important "to begin with the end in mind". Planning for product launch should begin on day one of the product concept. If the product concept has been properly vetted, then the design to cost (DTC) goal and projected volume product demand should be well understood at the beginning of the project. These two pieces of data, along with the upstream customer requirement, should drive the design, the process, and the 3-year product volume ramp plan. With these pieces in place, the design team can work toward a frozen design that meets the customer requirement. Meanwhile, the process team can be working concurrently to meet the projected launch date with a process capacity ramp plan that will exceed the projected volumes within the DTC goal. One approach is to design a scalable process that will meet 120% of the 3-year projected volume utilizing a single shift. This allows for flexibility to scale up the process capacity as demand grows while maintaining the option of a second shift for non-sustained periodic spikes in demand.

Failure mode effects analysis (FMEA) and process failure mode effects analysis (PFMEA) are great tools which lie at the core of any six sigma or quality program. These tools, when used properly, can provide valuable insight into the design and process weaknesses of a product. When coupled with a thoughtful risk analysis, the outcome is a stronger, more robust design and process. Even at the subassembly level periodic FMEA review is encouraged to ensure that all risk areas are being effectively addressed. Like all of the tools in this process, this information should flow from the top down. In other words, all of the elements of the FMEA should be derived from the top most customer-driven assembly down to the lowest component and subassembly. The information gained from the FMEA review should then be captured in a launch control document. As an example, if the FMEA review indicates



a potential risk to the supply chain by some unknowns in the process, the control plan may require the buildup of some "safety stock" to mitigate that risk. Because safety stock has a cost associated with it, which is preferable not to carry for the life of the product, it will be used as a launch control only, and there will be a call out point for when it is eliminated. Preferably, this happens in production once it is demonstrated that safety stock is no longer required.

Other tools, like the engineering process reviews, can be used as inputs to the launch plan. Often time these tools are either overlooked or conducted independently in a format that is not captured in the launch plan. Engineering process reviews should definitely be captured in a launch plan. This way, full advantage of the product knowledge on the design team and the process knowledge of the process engineering team can be taken. Too often, a problem is encountered later in the product launch cycle, only to discover that some individuals with product tribal knowledge not only knew about it, but took the time to actually document it in a separate format, like an engineering design review or an Open Issue List (OIL), that never made its way back to the readiness review. This represents a tragic missed opportunity, not to mention an effect on the bottom line.

Finally, conducting formal and periodic new product development (NPD) readiness reviews is an essential element to a successful launch. If possible, these reviews should be conducted in person, at specified stages of development, containing members of all interested parties in the product launch. The reviews can be divided into four phases - concept phase, development, pre-launch, and production phases. For the meeting to be effective, design engineering, process engineering, sales (for the voice of the customer), purchasing, and management all need to be represented. These meetings should update any changes in the design or process, the status of the product relative to the DTC goal, the schedule, and any customer changes or inputs. A readiness review format that utilizes a traffic light process embedded in an NPD checklist format is effective. (see Figure 5) In the NPD traffic light process, each element of the review gets assigned one of 3 colors: green indicates an element is ready, yellow indicates a potential risk with follow-up, and red is an at risk element with recommended actions. Any quality organization recognizes that this meeting must be clearly and formally documented for it to be of value. A standardized form that has all of the critical elements can serve to facilitate the meeting and record the results. The final readiness review occurs just prior to the program launch date, and contains the results of all the documentation and preparation to date. If the preparation steps have been effective, all the critical launch control elements should be coded green and any yellow should have launch controls in place. There should never be a launch with a critical element coded red.

Concept Phase NPD Review Checklist

FOCUS ELEMENT APPROVAL	GYR STATUS LIGHT	CONCEPT	REQUIRED FOR B LEVEL	RESP.	ENG RESP.	PROGRAM NEED DATE	TARGET DATE	COMP. DATE	ACTIONS (If Required)
Marketing	g	IDENTIFY CUSTOMER REQUIREMENTS	Yes						
Quality	r	REVIEW LESSONS LEARNED	Yes						
MKT Mgr	y	DTC STATUS	Yes						
Engineering	g	Q TOOLS	Yes						
Director	r	TOOLING MAKE / BUY	Yes						
Eng Manager	y	PROCESS BUDGET	Yes						
Sales	g	COMPLETE COMPETITIVE ANALYSIS	Yes						
Eng	r	KICKOFF MEETING	Yes						
Eng	y	DOCUMENT PROGRAM SCHEDULE	Yes						
Eng	g	PREPARE RISK ASSESSMENT	Yes						
Eng Manager	r	NEW ORDER CHECKLIST COMPLETE	Yes						
Eng	y	FMEA COMPLETE	Yes						
Eng	g	PFMEA COMPLETE	Yes						
Eng Manager	g	CUSTOMER CONTACT ASSIGNED	Yes						
Director		**CONCEPT PHASE EXIT REVIEW**	Yes						

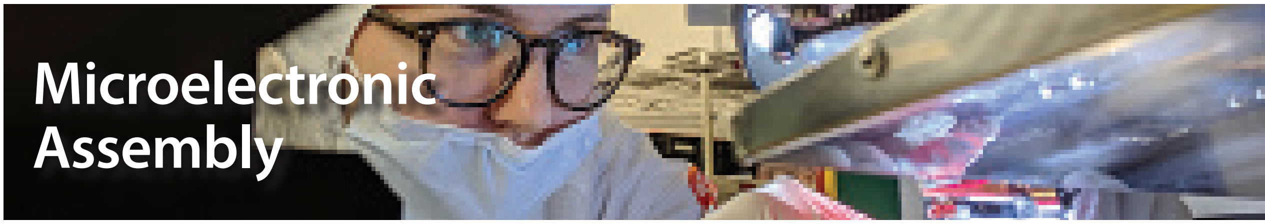
Figure 5. SMART Concept Phase NPD Review Checklist.

A robust design and a properly developed assembly process are necessary to ensure the success of a product launch. Whether building the entire product or a subassembly, there are always challenges that need to be overcome. It is important to have a thoughtful, well-documented plan that includes key elements – a 3-year product volume ramp plan, a capacity ramp plan, FMEA, PFMEA, risk analysis, NPD readiness reviews, control plans, and engineering process reviews – in order to have a well-executed product launch.

Microelectronic assembly suppliers need to work closely with their customers to help resolve product weaknesses or field failures in an assembly. They have to develop microelectronic assembly processes that will reduce or eliminate field issues and quality excursions. ISO quality organizations think about these scenarios as either corrective or preventative actions. Here, the operative word is action. In the former case, a corrective action is initiated to improve an existing weakness in a process or system. In the latter case, a preventative action is implemented in an effort to prevent the need for a corrective action. Therefore when helping customers develop a microelectronic assembly process, it is important to build preventative measures into the process from the start. As a general rule, prevention is always preferable to correction.

Earlier the concept of starting with the end in mind was discussed. This approach remains mindful of the desired outcome throughout each step of the development process. That principal is just as valid here. However, in designing a production process for microelectronics assembly it is also important to look backwards at the process. Those who are trained in classical quality tools, such as six sigma methodology, are acutely aware of the need to check all incoming materials. Looking backwards at the process means remaining ever vigilant of the quality and condition of our incoming materials, both from the source and from previous processes. This principal is vital to the health of the process and the balance sheet.

In all process steps it is usually assum-ed that all incoming material meets the prescribed minimum quality specification and that the material has been specified properly. If this is a valid assumption in most cases, then why is it that the majority of failures are still driven by incoming materials? Just because it is assumed that incoming material is "good" material does not mean that incoming material should not be checked periodically. It is advisable to establish an incoming material sample inspection routine for raw material or components that come from an outside supplier. This inspection routine should include an inspection of



Microelectronic Assembly

Incoming Inspection Data (2016)										
Upper support flange (37DR-75)										
		Inner Dia	Height	Dia	TP	TP	Height			
	Feature	Center hole		Side Hole	Side Hole	Cent Hole	Weld Protrusion (4 places)			
	USL	9.85	10.14	8.72	0.07	0.15	0.4			
	LSL	9.65	9.69	8.62	0	0	0.3			
Month	Week	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
Jan	1	9.770	10.040	8.625	0.010	0.065	0.310	0.350	0.320	0.370
	2	9.760	10.020	8.621	0.011	0.052	0.333	0.370	0.360	0.390
	3	9.760	10.020	8.700	0.020	0.041	0.313	0.322	0.310	0.384
	4	9.760	10.010	8.710	0.065	0.051	0.350	0.370	0.333	0.318
Feb	1	9.780	10.100	8.631	0.052	0.038	0.370	0.390	0.313	0.365
	2	9.760	10.110	8.645	0.041	0.019	0.322	0.339	0.350	0.360
	3	9.813	10.090	8.650	0.051	0.022	0.390	0.370	0.370	0.310
	4	9.780	9.980	8.718	0.038	0.011	0.384	0.390	0.322	0.333
Mar	1	9.760	9.750	8.717	0.019	0.062	0.318	0.384	0.370	0.313
	2	9.753	9.780	8.710	0.022	0.070	0.365	0.318	0.390	0.333
	3	9.752	9.912	8.631	0.011	0.033	0.313	0.365	0.339	0.313
	4	9.801	9.955	8.645	0.062	0.035	0.350	0.313	0.310	0.350
Apr	1	9.813	9.695	8.650	0.070	0.101	0.370	0.350	0.333	0.370
	2	9.780	10.010	8.645	0.033	0.132	0.322	0.370	0.313	0.322
	3	9.760	10.045	8.650	0.035	0.092	0.370	0.322	0.333	0.321
	4	9.753	9.980	8.718	0.055	0.087	0.390	0.370	0.313	0.369

Figure 6. Example of an Incoming Material Inspection Log.

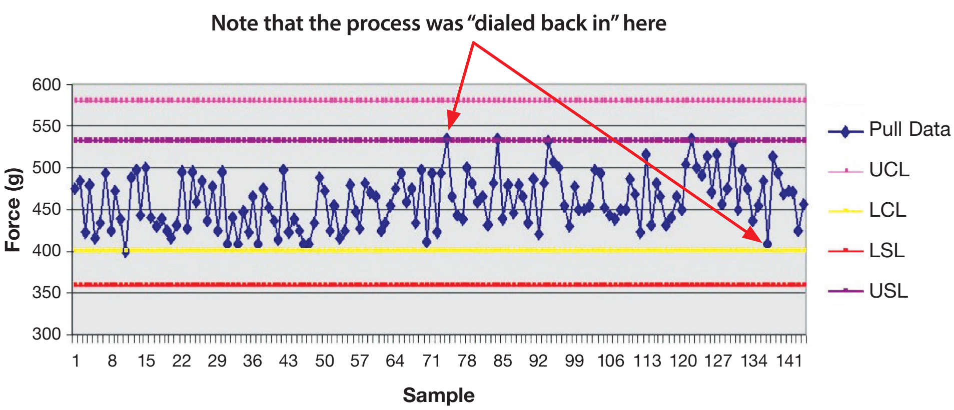


Figure 7. Example of early SPC data collected for a real wire bond process.

the critical characteristics of the material on a sample lot basis. It is always more effective and less costly to conduct sample lot inspection of incoming material than it is to discover failed finished goods at the end of the line. This is prevention, not detection.

Developing and maintaining a robust inspection plan that insures the integrity of materials from outside sources is vital to the health of any process. Shown in Figure 6 is an incoming inspection log for a machine tool part that is used in a sub-assembly. Selected critical dimensions are measured and recorded on a sample lot basis to insure the quality of incoming material. The incoming material is not being controlled because there is no control of the upstream process. It is simply monitored, and accepted or rejected back to the supplier. Incoming inspection is not process control.

What happens when the possible source of discontinuity is from an upstream step, internal to your own process? What can be done to prevent that? A commonly recommended tool is "Statistical Process Control", abbreviated as SPC. As the name implies, product sampling and statistical methods are used to measure and control a process. The goal is to set process limits (control limits) within the designs or customer limits, recognize the trend when a specific process is moving in an unacceptable direction, and intervene before design limits are reached. In other words, "dial the process back in" before it gets out of control. As an example using wire bonding, a periodic pull test can be performed on one wire of 3 parts per lot. When the wire bond pull strength trend line declines it serves as an early warning indicator that action needs to be taken. Perhaps the bond tool needs to be replaced. When the SPC control limit is exceeded, action is taken before the design or customer limits are reached. Shown in Figure 7 is an example of early SPC data, collected for a real wire bond process.

As was mentioned earlier, the focus is on prevention more than correction. There are a lot of tools available to achieve this goal. Developing a solid control plan for an assembly process is a great way to get started. During the design and development phase of the product, failure mode analysis tools like DFMEA and PFMEA can uncover most of the areas in which control needs to be established. This information can then be fed into a solid control plan, sometimes referred to as a "plan for success". Once the assembly process is in production mode and the control plan is being followed, data can be collected and fed back into the process for continued improvement. In the six sigma environment, this would be described by the acronym DMAIC, to Define, Measure, Analyze, Improve, and Control. Using these techniques the product or assembly begins under control, remains under control, and improves quality over time with reduced cost and greater profitability.

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