Loudspeaker Quality Control at ALMA '08

By Rob Baum

ALMA held an interesting panel discussion on January 6, 2008, entitled "Are You Shipping Defective Loudspeakers to Your Customers (or Are You Rejecting Good Loudspeakers)?," moderated by Steve Temme of Listen, Inc. The subject is important because it covers nuts-and-bolts quality issues in a broad sense—not just whether the part passes a test at the end of the line (after all the value has been put into it), but how to improve the entire process. Improving and maintaining the overall process from design for manufacture using statistical quality control results in fewer rejects, higher quality, and lower costs (yes, you really can have all three).

As manufacturing across many industries gets outsourced to China's vast industrial machine, it becomes increasingly difficult for manufacturing management to "close the loop" and keep a close eye on quality—since manufacturing is now often in another company, half a world away. Clear thinking and planning for the process of moving products from design to pre-production and then large-scale mass production become essential to avoid disasters on the factory floor in Shenzhen showing up by the container load six weeks later.

Quality and Deming

I was fortunate to have taken a course at New York University in 1989 with Professor W. Edwards Deming (1900-1993), arguably the founding father of quality manufacturing. Deming said many things still relevant today, such as "You can not inspect quality into a product" and "Costs go down and productivity goes up, as improvement of quality is accomplished by better management of design, engineering, testing and by improvement of processes." Deming also said, "It's always cheaper to do the job right the first time than to let defects enter the production line." Quality is achieved through tracking key statistical variations which provide near real-time corrective feedback to get to the root cause of variability in the production process, and also by following Deming's 14 points (which are beyond the scope of this article). Deming was proved right on all counts.

In the 1950s Tatsuro Toyoda, son of Toyota Motor Corporation founder Kiichiro Toyoda, studied statistics under Professor Deming after Dr. Deming gave a landmark series of lectures in Japan in 1950 to the business elite. At the time, "Made in Japan" was synonymous with cheap products of inferior construction. Professor Deming pioneered statistical quality control techniques, which were embraced in Japan, and enabled Japanese automobile manufacturers, particularly Toyota, to revolutionize their manufacturing processes and take substantial market share away from General Motors, Ford, and Chrysler starting in the 1970s and continuing today. Toyota passed GM in unit sales last year to become the largest automaker in the world by building quality, reliable cars. Dr. Deming, virtually unknown to the American people, was a major public figure in Japan. Deming is credited with assisting the rise of Japanese industry from the ashes and poverty of World War II into a world-class industrial powerhouse.

With this background, I can review the discussion that took place in January, prompted by three topics from the moderator, Steve Temme. I have made clarifications or supplemental comments by speakers. The panel is well qualified to discuss these topics due to experience. Three panel members have AES papers on the subjects discussed: Temme on measurement, Klippel on nonlinear distortion, and Laurie Fincham on speaker production testing (dating from the late 1970s!).

Topic 1: The importance of a good testing environment. What is needed? Physical setup, fixtures, enclosures (to reduce background noise), automation?

Chin Fa Cheng, Senior Acoustics Engineer, Shinhint: Investment in jigs or test-fixtures does not fundamentally solve QC challenges. Operators often focus on the wrong issues, and the underlying problems are never solved. The real solution is education throughout the firm, from design-engineer to line supervisors, to operators.

Laurie Fincham, Chief Scientist, VP R&D, THX Ltd.: Know that your setup is good, check setup at the start of every shift. Noise is your enemy. The production environment is challenging. Know what you are testing for. Test early in production to catch problems early. Do 100% testing; if you sample, there is the pressure of production to ship it anyway.

Wolfgang Klippel, Klippel GmbH & University of Technology, Dresden, Germany: There are two objectives in end-of-line-testing. First, the basic goal is to prevent shipping bad units to the customer. Here simple PASS/FAIL decisions using limits are sufficient. However, the ultimate goal is to avoid manufacturing defective units. Here diagnostics are required to find causes of the defects and to solve this problem by production control.

How do you reduce rejection rate? Find the physical cause. If you can get to the cause quickly, can you take corrective action?

Diagnostics based on nonlinear parameters—stiffness Kms(x) and force factor Bl(x)—reveal motor and suspension problems directly, e.g., voice coil offset. This information cannot be derived from harmonic distortion measurements.

Nonlinear curves are good for R&D but not for end-of-line testing. Although they provide comprehensive information, the full identification requires too much time (5 minutes). Complexity makes interpretation difficult. For example, an asymmetrical Bl(x) curve may be caused by coil offset or by an asymmetry of the B field. Statistical analysis of process stability (such as Cpk and Ppk) cannot be applied to curves.

An interesting alternative is the measurement of single-valued large signal parameters such as voice coil offset Xoffset (in mm) or suspension asymmetry (in percent) which takes seconds using the new Motor and Suspension Check (MSC). This information is corrective feedback to the assembling process to fix systematic errors and ensure optimal properties of each speaker.

Bob True, Chief Technology Officer, and Chief Quality Officer, Tymphany Corporation: You need good people first. You need to set up the system parameters correctly. A company test expert needs to be on site. You need to be able to quickly troubleshoot problems that come up. You need a good test technician or engineer to set up. You also need skilled line operators to work the test gear. They must understand a little of what they are doing and be able to communicate it to the setup guy. Give the operator enough time to properly load and unload the speaker from the test fixture.

Eric Chu, Customer Service Manager, EAV Audio (China): People are part of the test system, it's not just the software or hardware. And some people don't really know what they are looking at in the factories. Use legal products so you have access to help with the test systems. (And call the test system suppliers if there is a problem with online testing equipment—most of the time this will save the factory or customer's engineer a half day or more of work.)

PHOTO 1: The panel at ALMA.

Scott Orth, Systems Engineer and Test & Measurement Guru, Polk Audio: Design the test enclosure correctly to get good noise isolation. I've seen the noise in many test boxes have an effect below 500Hz—they are no good. Also watch your fixturing, look out for diffraction in the box mounting of the drivers (especially tweeters), and make sure they don't allow noise leakage. Make sure you can take the factory noise out of the measurements. Also, the operator needs relative quiet to hear defects.

Q: **Dan Digre, Misco**: what about clamping the speaker versus not clamping (automated or manual)?

Scott Orth: Manual works well if the fixture is made well. Better than holding by hand, make sure you understand the variation in the dimensions of the device under test—if it varies itself—and make sure the clamp can accommodate those variations.

Q: **Stu Lumsden, Polk**: Adhesives—How do you control them during the manufacturing process?

Wolfgang Klippel: Measuring the voice coil is simple, it is very hard to measure adhesives—hard to find a physical cause of everything. Express data in a way that is good for QC and process control, not for R&D. Keep descriptions simple.

Topic 2: How to define good enough (on the production line) to accept versus reject? Golden ears (listening) versus golden units (testing). Statistics. What to measure, test equipment, speed versus accuracy.

Scott Orth: Through use of a Golden Standard, but standards may differ at different places in the supply chain. Your goal is to maintain those standards and understand any differences. You need to sort out the golden sample (single one) versus all the others that may be used. All locations should have a standard unit calibrated to the one good golden sample. It is possible to correct for deviations in standard units by altering limits or applying EQ to tests.

What do you measure? Frequency response, rub and buzz, check for air leaks; maybe impedance and Thiele/Small parameters. We don't know enough about distortion and psychoacoustics—what level of distortion is too much? You need research.

Eric Chu: Golden units—It is important that factories handle the golden unit properly. It's easy for a factory to damage the golden samples since they are handled every day. If you can measure all, you should measure all, to collect data to find out what is variable and what needs to be controlled (and periodically check the complete test system).

Bob True: Gauge qualification—MSA (measurement systems analysis) is a set of activities we use to qualify any gauge and qualify everything that goes into a product spec such as end-of-line testing. Include stability (repeatability), and understanding your rate of drift to set the calibration schedule. Linearity: your device should be correct at loudest levels (not overloading any link in the signal chain) and at the softest levels (you need to have a low enough noise floor). Accuracy: in terms of end of line, it goes to impedance and frequency limits. For frequency response, it's the golden reference sample. Compare Z min to something traceable to NIST to ensure accuracy.

Relative consistency: gauge R&R—studies are time consuming but necessary to know what the gauge repeatability is. Statistical analysis of measurement error due to gauge variation and operator error is usually expressed as % of spec tolerance—i.e., for a 1Ω spec tolerance and 0.1Ω gauge variation, that's good (10%). At 30%, it's too much—you might let bad speakers out the door or reject good ones. Gauge R&R: make sure you measure the same thing. There might be a problem if you are breaking in a speaker suspension by making multiple measurements. Get around that by breaking them in ahead of time, and letting them recover for some time. It is well worth the time.

Vance Dickason: From a systems perspective, keep your reference. Quality control costs money. KEF, for the LS3 5A, would review past production records and ship an appropriate replacement part based on the original serial number.

Wolfgang Klippel: "What is good enough?" is a fundamental question which should already be discussed in the early design stage to tune the product to the particular market. The limits calculated by statistical investigations on good units at the end-of-line are a different issue. Standards defined by QC statistics assess consistency of production rather than minimal sound quality. For this reason we usually relax the standards if suddenly 50% of all units fail in automatic testing but all of those units sound acceptable. The tight tolerances used for the resonance frequency is a good example for

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this dilemma. The resonance frequency of automotive speakers may only vary a few percent in manufacturing, but vary more than one octave in the final application such as in the heat of Mexico or in the cold of Canada. On the other side we need the most sensible techniques for detecting rub and buzz, loose particles, and other defects which might be inaudible at the end of the production line, but may be a severe problem to the customer over time.

Laurie Fincham: Gauges and good procedures. This is hard to do within, say, 1dB. Reliance on acoustic measurement is quick, but may be the wrong way. Measure volts and amps, measure mass. These are simple and repeatable. You can get precision info even from weighing the whole speaker; use this in parallel with end-of-line frequency testing. Take multiple approaches to know what is going into the speaker.

THD—my personal view: it's overrated for speaker performance. We test for it, because we can, not because it's central to what we should be doing. We set up an experiment with a measurement microphone, and adjust the microphone and speaker level to be the same (as the amplifier output was turned up, the microphone gain was turned down). What was the difference? The tweeter was getting hot so it sounded a little dull. So distortion may be more properly thought of as noises out of the ordinary that the customer can hear. Look for that. Get it right at the beginning. The variable is the process if you get the component input parts right at first.

Chin Fa Cheng: During production, the more experienced QC staff can recognize the anomaly of SPL peak shifting in frequency. The problem is especially difficult to tackle when accompanied by a dip in frequency response. This raises two problems: 1) fundamentally solving the shift, and 2) setting (floating) limits to not reject good product. Advanced training from professionals would improve overall efficiency.

One of the benefits of 100% checking, especially for drivers made in the same factory as the final product, is that QC staff reports low F.o.R. ("fall out rate") when compared to no checking on driver level, only checking on final product. One of the reasons is when the whole company knows it's a 100% check, everyone, top to bottom, will put in extra effort automatically. From setting up the line to planning, you need to take various preparations, such as weighting each dust cap before assembling them to driver to avoid multiple inserts.

Q: **Phil Bunch**: What is the target for noise levels inside a test box?

Steve Temme: Depends on what you are trying to measure. Customers want test systems that can reject noise. In rub and buzz, sometimes you can hear distortion that is 60dB below the fundamental. So if your background noise is 45dB (background noise can rise to 85dB below 500Hz), then you need a fundamental at 105dB.

Laurie Fincham: It's about signal-to-noise, not just about the chamber—get the microphone closer, you will get better signal-to-noise. If the acoustical measurement is no good, make an electrical measurement. Ensure the process of making the product is good. Put the microphone close to the speaker or inside the speaker vent if you must. You can listen inside the box—use a stethoscope. It is not all about speed. Good practice on the line is key.

Wolfgang Klippel: All the driver end-of-line testing I have seen—they put the mike close to the speaker already. We can only detect rub and buzz in the acoustical domain, can't do it electrically.

Laurie Fincham: Then separate the tester from the noisy area. Get the microphone in the right place. You need a really good fixture. Jig it really well, think of the operator. See how the operator works and see how they use it, make it easy for them.

WK: Production and test are usually co-located. It would be ideal to place end-of-line testing in another room, but this is difficult in practice.

Q: What about electrical power being too noisy in China?

There were some yes and some no answers among the group.

Scott Orth: Insist upon a power supply that is good enough to not sag, say under high power testing of a subwoofer.

Q: High frequency spikes that come through AC are significant. We have difficulties with our electrical testing.

Steve Temme: Try a spectrum analyzer with no signal.

Q: Let's separate performance from rub and buzz. What does the customer want, and why will he return product? Most important is to avoid rub and buzz, and you must test 100% for that. Regarding THD and so on—does this affect making the sale, or a return? If the customer gets product home and hears a rattle, he will return the product.

Q: Should the golden samples be measured periodically?

Laurie Fincham: Make 100 of them and measure them twice a day. It should be the "brass" standard, the most common. Make 100 or 1000 drivers and measure everything—flux density, VC max (excursion), then do the analysis and figure out what will happen. Sort the results and pick the brass standards. If the reference is actually moving, use these references every two hours. If in doubt, don't stop the line; take a questionable product to the lab. When we started with computerized measurement at KEF, we saw how variable our products were. However, you can use the information to get to the root cause of variability.

Topic 3: How to get everyone working together? Including engineering, manufacturing, management and the customer, procurement/project manager, design engineer, QC test engineer. How to document everything?

Bob True: How do we get everyone to work together to not make bad speakers? The goal is to not need a test booth. Strive toward zero defects. We use data we collect at the end of the assembly line. You can then connect it to data from incoming QC and track back to what went wrong. This data is helpful. We look at the data every month in a Pareto sense (80% of rejects are caused by 20% of problems). Where are the highest rejects, what was the biggest problem? Sometimes you must go back and focus on one or two critical models. However, it is more efficient if you look at the larger family of reject causes and address them at the fundamental level, then the improvement is across multiple products.

Tymphany has cut its reject rate in half each year for the past three years and we are looking to do that again this year. We are always about continuous improvement—finding the root cause so we don't make the same mistake again. We have design for manufacturability; we keep failure mode analysis data. Where are the critical parts of our process? Use this in the design and product development process.

Wolfgang Klippel: When I started as an engineer in an East German loudspeaker factory 25 years ago, I learned a lot from the manufacturing guys who were located near loudspeaker development.

If development in Europe is separated from the production in China, we lose this feedback. This is even worse if development and manufacturing are not part of the same company and both parties fear a loss of know-how. Small companies which still combine development and manufacturing have an advantage in this point.
Laurie: I agree—I used to work in a factory where we all worked together. We are now 10,000 miles away and don't speak the same language. How do you let people know what you want? Use a camera. Go there, show up. This helps to diagnose, not to fix. What is going wrong, why, and how to fix it? This is a completely different learning curve, but you should avoid a rush to blame production. Be nice to production: you will get the cooperation you need to solve the problem. Get to know the people. Experience is worth a lot. I want to set up a system so there are no problems in the first place, not prove someone did something wrong.
Chin Fa Cheng: Customers do not demand enough paperwork from the factory. Engineers in the factory may want to help you, but customers must ask for it so the factory will do the work.
Scott Orth: Use specifications and procedures carefully, after considered discussion, so there are no surprises in production. Send them to the manufacturer, talk to them, and make sure that each point is understood. For example, make sure they understand you want 100% testing. Put as much detail in as you can, and discuss it with the manufacturer.
Eric Chu: Try to collect as much as you can in data and photos for later reference.

Q: **Peter Larsen**: When you are talking about reducing systems to standards, you can simulate the system ahead of time and add tolerances, to predict what you can expect from production. Engineers look at specs, they see 8Ω and know tolerance is 20% and they make it 6.4Ω on purpose (to play louder in the store). They want to find out how low we can go.

Chin: My experience from high quantity runs is that, while the voice coil DC resistance can be held within 1%, many engineers design a nominally 8Ω driver with a real resistance 20% lower, 6.4Ω.
Eric Chu: The manufacturer can deliver 1% tolerance; many suppliers are very good.

Q: **Steve Hutt**: Discussion is from design and development outside China, built in China. There is one American OEM in the room and one firm that manufactures in the US and Mexico. Anyone in the room not based in China? Dan Digre has a factory in the US.

Scott Orth: We are using China as an example, but it applies to all factories.

Q: **Stu Lumsden, Polk**: We talk about China since the business has moved there. But other factories are represented by companies that are long-time members of groups like this and speak the same language, or everyone was under the same roof, with engineering responsible for the design being successfully manufactured. This is true anywhere in Asia since there is a cultural gap.

Audience comments:
Going out to the factory floor of integrated firms provides better feedback.
We try to be proactive about changes in frequency response.
Even at the front end of the design process, design for manufacture is not emphasized as it used to be when production and design was in the same building.

Chin: On the full-product level, especially with a built-in amplifier, QC has extra challenges. The speaker normally cannot be tested due to its being buried in an enclosure. This is where design-for-manufacture must include design-for-QC, where tiny holes on hidden surfaces (e.g., bottom or inside battery housing), where test pins can access the speaker terminal at the amplifier's output. Another difficult QC case is operator's non-awareness of amplifier turn-on delay. A QC operator may place the DUT (device under test) onto a test jig and measure so quickly that a good device will fail. This is why engineers must be on the QC line to oversee all sorts of unexpected issues, as stated by Laurie Fincham of THX.

Q: How do you set the right limits?
Laurie: What is reasonable from a manufacturing point of view? Measure what it does or how it is made. If they put the right parts together and the parts are within spec (say, of a crossover), then the final product will come out within spec. Engineers are not trained to set the proper limits. Bell Telephone needed 0.1dB tolerances for repeaters—and was successful, back in the 1930s. See how they did it. We measured everything. If you don't understand how the system varies with component variation, go back and understand.

Summary

There was a lot of hard won, good advice at this lecture from an excellent panel. Because the era of easy and cheap expansion of the Chinese industrial base is over due to rising prices for everything in China (labor, electricity, copper, steel, and so on), manufacturers and governments there will be faced with stark strategic choices about how best to prosper in the second phase of market-based Chinese economic growth. It is likely that some vendors will not change anything, and continue to struggle. It is also true that some of the more far-sighted firms will attempt to improve the way they build products from a systems perspective—building quality in. Those firms that are successful can add more value to their foreign customers' designs, not just surviving, but prospering in this second stage of development—despite rising prices and an appreciating currency.

Barring political and social disorder, the cream of these firms may build the foundation for a third stage of modern Chinese economic expansion. Quality domestic manufacturing may execute a Chinese-based design, sold under a Chinese brand, to the large domestic as well as foreign market. This may power an emerging wave of firms that will go on a global offensive, at first working with, and then displacing long established European, American, and Japanese brands. American multinationals did this to complacent European firms in the 1960s. Japanese firms did this to American firms in the 1980s, for example, with Toyota displacing GM in autos.

Lenovo was the first, buying out its blue-chip US customer, IBM's ThinkPad (laptop) division. If the Chinese are able to take the high road, and build quality products that customers actually want to buy, the Lenovo deal will not be seen as an aberration, but the first of many in a very different and far more competitive world. It is a never-ending dynamic—behind the Chinese will come Indian firms, especially in software, and smaller players such as Vietnam, fueled by Taiwanese investment. Those firms that take the hard path of quality will live long and prosper, regardless of which country they may be from.

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