Quality of Conformance in Vibration Testing

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Despite our best efforts to "do things right the first time," much time and effort are spent correcting errors. When designing a new product (even with extensive computer modeling), design engineers can never be certain of the results until a prototype is built and tested. Even then, careful work by test engineers is required to avoid painful corrective actions further down the road. Reducing the time and effort spent correcting errors is the focus of quality of conformance and it requires more than simply knowing proper experimental techniques.

Understanding Theory. Before planning actual experiments, a test engineer should have a good understanding of the phenomena being studied. Even a simplified theory can provide helpful facts and equations for designing experiments and interpreting the results. Consider the case of a company producing fans. The rotational speed of the metal blade assembly was designed for 900 RPM, but the customer asked that it be tested at 2700 RPM for vibration fatigue effects of the blade assembly's unbalance. The technician charged with finding an adequate motor purchased one 3 times as powerful as the existing motor, yet the new speed was just 1300 RPM. He bought another motor that was 10 times more powerful than the existing one, but the speed was only 2000 RPM. The problem was finally solved after purchasing a motor 30 times more powerful than the existing one. The technician had no idea that fan performance at a new speed can be estimated with simplified "fan laws," one of which states that the power required is proportional to the speed cubed. So to triple the fan speed, 27 times more power (3^3) is needed.

Nobel Prize winner Wilhelm Roentgen joked that three important things are needed to obtain true experimental results: "theory, theory, and again theory." On the other end of the spectrum was the great inventor Thomas Edison, who freely admitted that he was not proficient in mathematics and theoretical science: "The way to find out how to do a thing is to try everything you can think of." Edison persistently applied this time consuming "trial and error" method to his work. Nikola Tesla, another great inventor of the time, commented that he was "a sorry witness" to Edison's procedure, "knowing that just a little theory and calculation would have saved him ninety per cent of the labor." At one point Tesla was hired by Edison, but friction soon developed between the two and Tesla eventually lost his job.

Cross-Functional Teamwork. The problem with the fan motor would have been quickly fixed if the technician had discussed it with one of his engineering colleagues. The experience of others is a great resource for dealing with similar problems but it must be tapped to be useful. Teamwork among the right personnel can help utilize past experience while fostering new ideas to deal with new problems. In many organizations there are formal teams consisting of both engineers and managers. But, teamwork should start much sooner on an informal level, such as discussions between colleagues. Certainly, the "human factor" is important for productive teamwork – sometimes it is not easy to pair the right people with the right problems at the right time. Allegedly, Edison and Tesla were once chosen to share a Nobel Prize in physics but Tesla declined because he did not consider Edison a scientist. Neither of them received the prize and the two individually great men failed as a team.

Test engineers used to work closely with project, quality, manufacturing and FEA (Finite Element Analysis) engineers. While working as a NVH (Noise, Vibration and Harshness) engineer near Detroit, I collaborated with other engineers on a regular basis with very satisfactory results. I often invited project engineers to the shaker rooms to demonstrate potential failure problems, allowing them to develop feasible design improvements while observing real vibration modes. FEA engineers also need the results of experimental modal analysis. Even if they can predict natural frequencies, it is not possible for them to precisely estimate structural loss factors. Working with talented FEA engineers from Germany on a Mercedes Benz project, I found that their computer model produced inaccurate results because the loss factor was set to about twice its measured value. Thus, the computed stresses proved two times lower than in actual practice.

On the other hand, FEA was very helpful when I tested MEMS (Micro Electro Mechanical Systems) sensors. For the shaker test, the miniature parts were installed on a single-axis shaker and their vibration response was detected with a laser vibrometer that only measured out-of-plane displacements. FEA techniques produced vivid pictures of both out-of-plane and in-plane vibration modes that were very helpful to the analysis. In both cases, teamwork produced more accurate, detailed results than working alone.

Checking Techniques Repeatedly. Routine maintenance and calibration are not always adequate to ensure accurate techniques. One of our consultants, an experienced electronics engineer, measured the quality factor of a MEMS silicon actuator in vacuum by processing the amplitude decay with time and obtained Q ≈ 88,000. Using the same experimental data and a traditional equation, I obtained Q ≈ 96,000. Both results looked reasonably close, but since the difference was not minor I asked him to explain his calculation. It was found that he had made two mistakes in the same formula that almost compensated each other. The calculation constantly yielded a value that was 92% correct. The consultant had derived his formula long ago and utilized it in numerous test reports. Since his results were close to the real values, nobody paid attention to the small discrepancy. Such a situation is not unique and we should occasionally check even the most routine procedures.

Using Simplified Equations. With the advent of FEA modeling, many people completely neglect the simplified mathematical models utilized before computers became so widespread. The reason is at least twofold: (1) Finite element procedures are now an important and frequently indispensable part of engineering analysis and design. (2) Many people lack a good mathematical background (in my opinion, a main problem of our high school and undergraduate education).

In my practice, I always check the FEA results with manual calculations based on simplified engineering models. Once, a young FEA engineer computed the heating time for a miniature, structurally complex MEMS silicon element as about 20 sec. The result looked reasonable to him but seemed doubtful to me. Before designing the test setup, I applied a very simplified equation and obtained a heating time on the order of 0.1 sec. The engineer checked his model and found a mistake in the boundary condition. After fixing it, his result changed to 0.2 sec. While simplified equations are not as powerful as FEA models, they can still serve as important checking procedures.

Writing Detailed Reports. One year after my company issued a vibration fatigue test report, the customer asked which fasteners were used to attach the experimental units to the shaker. Regrettably, this 'detail' was omitted in the test setup description, the photos were not clear enough for visual inspection and the test engineer did not remember. While it seemed like a minor detail at the time, fastener size proved important because it may affect the stress concentration in the brackets. To appease the customer, we spent two weeks running the test again.

The quality of test reports is just as important as the quality of the testing.

When writing a report, the test setup description should be detailed and well-illustrated with close-up photographs, preferably using a macro camera lens to show small details. For presenting numerical data, tables are better than graphs where the actual numbers are important. Graphs should illustrate the behavioral tendencies rather than just experimental points connected with lines.

Writing tables can be tedious, but consider the following case. When Dmitri Ivanovich Mendeleev became a professor of general chemistry at the University of St. Petersburg, he was unable to find a straightforward textbook for his students. He thus began writing his own, including the goal of creating a relatively simple table of the existing elements so the students could easily study their physical and chemical properties. After many tables and graphs, in 1869 he finally created the famous Periodic Table of the Elements and discovered the important relation between their atomic weights and other properties.

The Importance of Teaching. The previous examples show how teaching can help us better understand 'common' knowledge and even make great discoveries. My university professor of thermodynamics told his students, "I often learn from you more than you learn from me." We did not understand his point until he offered an example, "You do it by your 'naïve' questions. Even if I reply to them immediately, I continue thinking and finally get a new solution to the same or even completely different problems."

Once he took some of us to his small laboratory room and showed a compact experimental setup in the corner. "Thank you very much," he said, "now it's small and relatively cheap." The test setup as initially designed was bulky and expensive. While trying to improve it, the professor wrote a simplified homework problem for us. Fortunately, he missed one 'principal' condition in the description. Nevertheless, we unraveled the problem and obtained a reasonable solution. After checking it, the professor suddenly realized that the missed condition was mainly redundant. As a result, he was able to exclude some mountings and devices from the original test setup to simplify the overall design.

Conclusion. Quality conformance involves an understanding of the theory, use of colleagues' knowledge, double checking your techniques and equations and adhering to the details when writing reports. Doing so is a much better investment of your time than correcting mistakes after the fact. SV

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