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# In Pursuit of Perfect Precision: An Anecdotal History of the Mahr Federal Precision Measurement Center

Thomas Rankin

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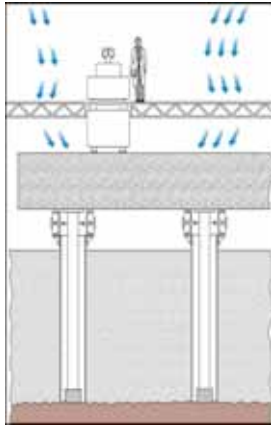
planning and construction of the center “are no longer with us.” No one recalls exactly when the center was built, or what it cost (although Mahr Federal’s “metrology” corporate culture is so meticulous, the records are probably still in a file somewhere). Even why it was built has become the subject of some controversy. One story — that the existing metrology lab of then Federal Products Company had to be replaced when vibration from nearby highway

construction made it untenable—has turned out, says Christy, to be “a total fabrication.”

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sophisticated equipment ever devised, as well as some of the most mundane. The company was privately owned then, and no expense was spared. "But to replicate it today you'd probably have to be out of your mind," says Christy.

## The Structure

The known facts are that the Precision Measurement Center was completed in the early 1960's with the intention of eliminating, as much as humanly possible, those errors in the precision measurement process caused by environmental factors such as temperature, dust and vibration. Built in the basement of the company's manufacturing facility in Providence, RI, the Center is physically isolated from the surrounding structure. All measurement equipment rests on a five-foot thick concrete slab just below the floor that weighs nearly 375 tons and is supported by three, 30-foot tubular steel columns that sit on bedrock.

This elaborate construction eliminates the influence of external vibrations which could cause measurement inaccuracies, and even eliminates the influence of laboratory personnel moving about the room. Because the slab is supported on bedrock, other disturbances such as highway traffic and heavy equipment in the adjoining factory do not adversely affect the high accuracy gaging equipment.

Air temperature and humidity are also tightly controlled. A complex air conditioning, circulating and filtration system maintains temperature at  $68^{\circ}\text{F}/20^{\circ}\text{C} \pm 0.2^{\circ}\text{F}$  and relative humidity at  $40\% \pm 10\%$ . Air cascades through the room from ceiling to floor, replacing itself every half-minute. This vertical downflow eliminates stratification, controls dust, and provides a barrier of clean air between sensitive gages and technicians.

A member of the Mahr Group, known worldwide for its expertise in providing dimensional measurement solutions, Mahr Federal uses the center for its own calibration work, and also offers commercial inspection and recalibration services for dimensional standards — including gage blocks, master rings, discs, plugs and balls, cylindrical form

and precision reference specimens and surface roughness standards, as well as for a wide range of gages.

## Plans for an Early Laser Interferometer

But the truth about the lab's construction, said Christy, is that it was the result of an unsuccessful product development effort. "In the very early days of lasers, we were trying to build a very high accuracy laser interferometer," said Christy, "one which would resolve to sub-microinch levels. Our plan was to have something better than anyone else, and we were going to use that device to calibrate our high resolution electronics: things like electronic levels and the electronics that go into a gage block calibrator.

"This was in the days of extreme optimism about lasers," Christy continued, "and the thought was that you could do anything with these new tools. In fact, you couldn't. The precision of the optics necessary to achieve tenth of a microinch resolution on a laser system was not possible with the technology available at that time. So that project never happened, but in preparation for it, we built this super-isolated 'I-do-not-vibrate' laboratory."

## A Mechanical Microinch Calibrator

The need for such high precision in these measurements stems from the traditional gagemakers' "rule of ten" which stipulates that any measuring device must have an accuracy (or resolution) at least ten times greater than the thing being measured. As a practical example of this, say you measure parts with a micrometer accurate to fifty-millionths of an inch ( $\pm 0.00005''$ ). To calibrate that micrometer, you would use a set of gage blocks typically accurate to six-millionths ( $\pm 0.000006''$ ). To calibrate those, you would need a gage block comparator capable of measuring to a millionth of an inch and if—as is the case with Mahr Federal—your business involved making those gage block comparators, you would need to somehow measure to within a tenth of a microinch.

As it happened, while this laser development project was underway, two other Federal Products engineers—Arnold Judkins and John Worthen—designed a mechanical device that could accurately move one tenth of a microinch. Brilliant in its simplicity, this Microinch Calibrator (photo on page 54) uses "nothing more sophisticated than a standard one inch micrometer screw and a 1000 to 1 demagnification lever system," said Christy. Housed in a metal box about four feet long and made of invar—known for its extremely low coefficient of thermal expansion—the mechanism incorporates three knife-edged, second-class levers, hinged at one end and "folded" to save space.

When the micrometer screw is run its entire one-inch length at one end, the high-resolution measuring pad (there are three) at the other end moves a thousandth of an inch. When the micrometer screw is moved one thousandth of an inch, the pad moves a millionth of an inch. "And when you move the screw a tenth of a thousandth of an inch," said

Christy, “the little pad moves a tenth of a millionth of an inch. There is no hysteresis and you can actually reproduce that tenth of a microinch mechanical motion day in and day out, and we have been for the last forty years.”

But being metrologists, Messers Judkins and Worthen were not content to simply make a device capable of moving a tenth of a microinch: they had to know how accurately it produced that motion. “The question when they built it,” said Christy, “was, ‘how do we know it’s as good as we think it is?’” There being no other device at that time (this was 1962) sophisticated enough to duplicate its measurements, let alone calibrate it, they did the next best thing and packaged it very carefully and drove it to the then National Bureau of Standards (now NIST) in Washington, D.C.

Using their most sophisticated interferometry and statistical means, the Bureau conducted a three month study of the instrument—the report of which is still available—and concluded that the readings on the Microinch Calibrator “are accurate to  $\pm 0.15$  microinch.”

## The Flat Earth Society

But the pursuit of perfect precision can sometimes yield strange results, as happened in one of the more storied incidents of the Center’s history. It started when technicians set up a highly sophisticated electronic level capable of detecting up to a tenth of an arc second, or  $1/36,000$  of a degree. In testing the system, they found they were getting inconsistent data. They double and triple-checked the instrument but got the same results. More curious, the data followed a pattern that seemed to indicate a change in the attitude of the room twice a day.

“When they built the room, they had some professors from MIT instrument it with all kinds of accelerometers and seismographs to see if the location was seismically stable,”



Dimensional measurement for gage block calibration is possibly the most precise mechanical measurement process on the planet. The environmental conditions under which it is done are as controlled as possible, and the equipment used, such as this Mahr Federal Model 130B-24 Comparator, is the absolute best that can be made.

said Christy. “But a seismograph only tells you if the ground is shaking: it doesn’t show anything about tilt.

“So they couldn’t figure out what caused it,” Christy continued. “They tried everything they could think of. At one point, they even had all the employees move their cars to the other side of the parking lot to see if people coming in and leaving work could cause ground loading and a tilting of the environment. But they discovered it didn’t make any difference where people parked.

“Then, in frustration, somebody made the off-handed comment, ‘well, it must be the phases of the moon.’ And somebody else said, ‘Hey, wait a minute—maybe it is!’”

And sure enough, the data not only indicated a twice daily change in attitude, that data correlated perfectly with the tides rising and falling in Narragansett Bay, less than a half-mile away. The weight of all that water was depressing the mantle of the earth just a tiny bit, and the instrumentation in the Precision Measurement Center was picking it up.

## Have You Got a Spare?

One of the more mundane aspects of the Center’s structure has to do with the air cushioning system which dampens horizontal vibrations and balances the giant slab clear of the surrounding walls. This system is comprised of nine inflatable tubes, positioned around the three supporting columns at  $120^\circ$  intervals, which press outward against the caissons which surround the columns.

Although this system is effective, “it’s not very sophisticated,” said Christy. “The tubes are the inner tubes from Piper Cub tires. I mean, they’re not *like* small aircraft tire inner tubes: they *are* small aircraft tire inner tubes. And sometimes they go flat, just like all tires. They age, and they leak. You can go down under there and hear them hissing. And that’s not good because if one springs a leak, the whole slab moves. They have nine pressure meters on the wall upstairs so you can see which of your tires has gone flat. Then the maintenance people have to go down and change the tire.”

Once a new tube is installed, the air cushioning system has to be rebalanced. But the air pressure gages alone are not sensitive enough for this task. A piece of copier paper is used as a feeler gage. They pump the tire up until they can slide the piece of paper up between the slab and the wall. That’s all the clearance you need to isolate for vibration.

Occasionally, however, tire problems involve more than just leaks. Once, the city of Providence was demolishing some old high-rise buildings with dynamite. The dynamite created a ground shock wave and six of the nine tires blew. The people in the lab thought there was a gang war in the basement because it sounded like rifle shots.

## Directly Traceable to NIST

Most days, however, the Center goes routinely about the work of calibration of dimensional standards and equipment, both its own and for customers. Walk into the Center and the atmosphere is quiet, almost sterile. You can feel the

downward rush of cascading, filtered air. The equipment is spotless and the technicians in their light green lab coats, go quietly about their business. There is little chatter, no horseplay. Masters and equipment are handled with forceps and wiped carefully with lint-free cloths. Faceshields screen sensitive comparators from the heat of operators' breath. The whole environment speaks of precision.

In addition to the Microinch Calibrator which is still in daily use, dimensional measuring equipment in the Precision Measurement Center includes a Mahr 828 CiM that can certify ring diameters to an uncertainty of 8 microinches, and a number of Mahr Federal Model 130B Gage Block Comparators, widely recognized as standards in the industry.

Dimensional form features are measured by several instruments, including a Mahr Federal MMQ44 Formtester which measures roundness to within  $\pm .01$  microns, straightness to within .25 microns per 100mm, as well as cylindricity, flatness, concentricity, coaxiality, radial run-out, total radial run-out, axial run-out, total axial run-out, parallelism, perpendicularity and angularity. The system also adheres to both National and International Standards.

Surface metrology is performed by systems such as the MarSurf® LD 120, a new upper class high precision contour and roughness measuring station with integrated laser system. Roughness and contour are determined with a single stroke to within 2nm resolution. Also used frequently are a Hewlett-Packard Laser, a Heidenhain Probe, as well as a number of other digital and analog precision instruments.

Mahr Federal Grand Master Gage Block Sets are regularly calibrated at NIST, providing direct traceability. Mahr Federal's calibration system is certified to ISO.IEC 17025 and ISO 9001:2000. Certification bodies are NVLAP for 17025, and NQA, USA for ISO 9000.



The compact MarForm® MMQ44-R Formtester from Mahr Federal measures roundness to within  $\pm .01$  microns, straightness to within .25 microns per 100mm. The system also measures cylindricity, flatness, concentricity, coaxiality, radial run-out, total radial run-out, axial run-out, total axial run-out, parallelism, perpendicularity and angularity, all to both National and International Standards.



This Microinch Calibrator uses a standard one inch micrometer screw and a 1000 to 1 demagnification lever system to reliably produce mechanical motion as small as a tenth of a millionth of an inch.

## Occasional Excitement

The routine work of precision measurement is occasionally broken up with a little excitement. When the city of Providence recently announced a major sewer project that would involve digging a 50-foot diameter, 2-mile tunnel, some 200 feet down, the metrologists at Mahr Federal raised a cautionary finger. Would the project involve any blasting, they wanted to know, or any kind of work that might shake the earth?

In response, the contractors sent over a team of engineers who instrumented the shop floor and the lab with seismometers and set off a series of test blasts. "You could definitely see the vibrations on the shop floor," said Christy, "but not in the lab. Blasting a half mile away was no problem."

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