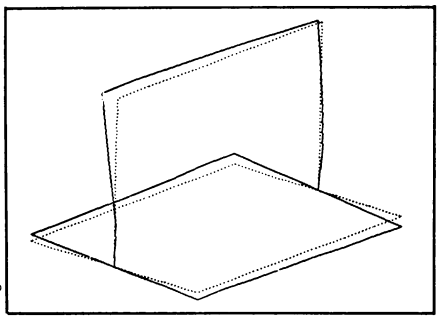
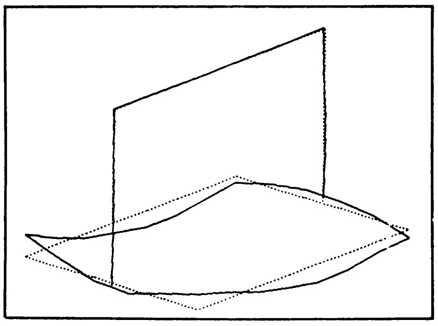
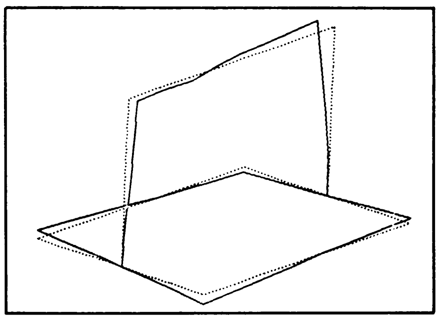
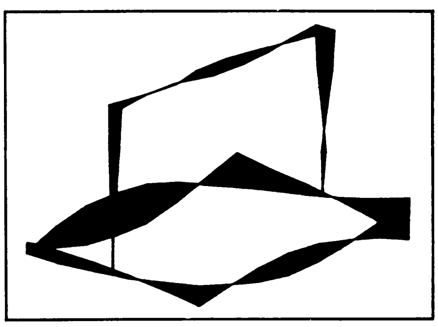
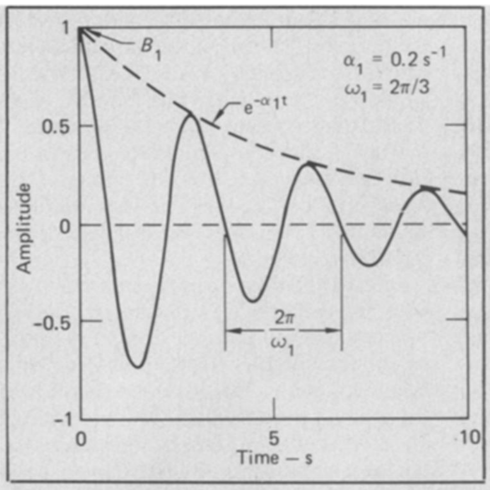
Analyzing Their Vibes

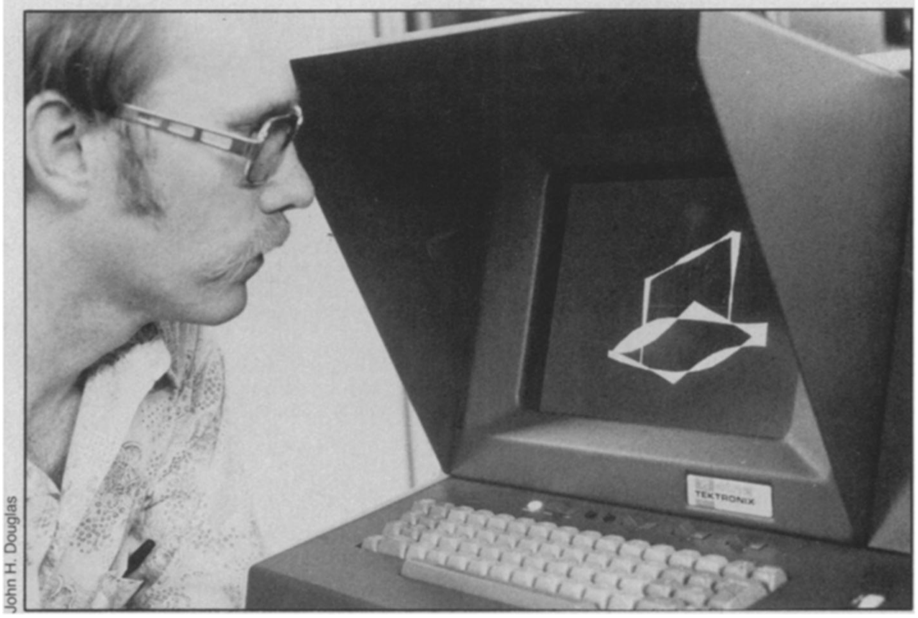
Diagrams: LLL

Almost 200 years ago Prony suggested a way of analyzing damped sinusoids to determine individual modes of oscillation. Modern techniques make it practical.

BY DIETRICK E. THOMSEN



Data that represent the sum of a large number of damped sinusoids like the one immediately left can be analyzed by Prony's method. A computer at Livermore stores data representing individual vibration modes of a T-shaped metal plate and will add them at will (far left column). Still or moving pictures of the vibrations appear on the screen viewed by Darrel J. Lager (below).



John H. Douglas

Gaude, Gaudy, domini in laude.

So runs the inscription on one of the bells in the tower at Fenchurch St. Peter, the location invented by Dorothy Sayers in *The Nine Tailors.* Latinists will recognize the inscription as a bilingual pun on the name of the donor of the bell, one Gaudy, and it is quoted for irony's sake, because the bell that is here bidden to rejoice is, along with the others in its tower, the murder weapon. The vibrations of Gaudy and her companion bells dispatch the victim, who lies bound in their chamber as they ring a New Year's peal.

Sayers's fictional bell, which, she says, was founded in the 16th century, vibrates when struck with a hammer. At the Lawrence Livermore Laboratory a metal plate of definite 20th century provenance vibrates when it is struck with a specially instrumented hammer. The physics of the hammer and the plate has been studied almost since Sayers's bell was founded, and the mathematical method that the Livermore scientists are using is almost as old, but the proceeding is as modern as the latest computer program. In fact, it is one of the latest computer programs. The procedure is called PARET (parameter estimation technique), and it promises to tell all kinds of things about physical systems and objects by analyzing oscillating signals that come from them. (That instrumented hammer could be used to tell the difference between a bomb and a peaceful nuclear device — no this is not a roadrunner cartoon; this is for real.)

There is an inherent complexity to vibrations of this sort. The motion of any point in the bell or the plate is the combination of a large number of modes of vibration, each with its own amplitude, frequency and decay time. Each mode is determined by some characteristic of the object, and if the modes can be analyzed much can be learned about the physical characteristics of the object.

Each individual mode can be described mathematically as a damped sinusoid (or, alternately, an exponential of a certain kind.) That is, they are waveforms that gradually die away as time passes. (Everyone knows that the sound of a bell gradually ceases unless it is repeatedly driven by strokes of the clapper.) In 1795 the French mathematician R. Prony devised a method for analyzing the data to get out these individual modes.

But "not much was done until comparatively recently," says Andrew J. Poggio of Livermore. "People walked away because of noise problems. We were a little naive. We didn't walk away." Poggio and his colleague Darrel J. Lager were looking for a means of analyzing data resulting from experiments in which they used electromagnetic fields to try to sense underground discontinuities such as forgotten tunnels, mine chambers, heavy rock deposits, etc. (More about this in a later article.)

The noise, unlike various kinds of spurious behavior by the real data themselves, is hard to analyze out because it does not have the exponential character of the real data. Unlike, say, a high-frequency component of the vibration that masquerades as a low-frequency one because of insufficiencies in the rate at which the data are sampled, a noise signal does not decay away. It just stays. So it can't really be handled by a system designed to discriminate among exponentials.

The way of getting rid of the noise, Poggio and Lager found is to take repeated overlapping "slices" of the data and average them together, a so-called moving-window technique. In this way the data points that represent something real tend to stay in place and build up. The noise just becomes a scatter of points. "The strong modes, the ones really characteristic of underlying data really stayed pretty solid," Poggio says.

One of the first experiments they did with the method was to analyze the vibrations during the San Fernando earthquake of 1971 of the 21st floor of a hotel in Los Angeles. Fourteen seconds of the shaking were studied—out of a total of about a minute, the data being analyzed in ten overlapping frames or windows, the first of which ran from 16.2 to 27 seconds after the earthquake began, the last from 18 to 28.8 seconds. The analysis successfully identified several different modes of vibration, where the previous literature had predicted only one, the strongest. Furthermore, it found some modes with negative decay constants — that is, during the sampling time at least, their strength was increasing rather than decreasing. That phenomenon is still being investigated, but it seems from first analysis that other modes were transferring energy to these modes.

Such data are easy to store and transmit, too. Each mode is characterized by three numbers, its complex amplitude, which measures more or less the strength of the hit, its frequency, and its decay constant, which measures how long it takes to die away. Store these in a memory, or transmit them over telephone wires, and you can describe the physical characteristics of the object. "We can characterize all the data by a small set of numbers and transmit them — if they are damped sinusoids," Poggio says.

Analyses of this kind go much farther than helping to design earthquake-resistant buildings. Take the question of the test ban situation in which a not-to-be-opened device is presented as a peaceful nuclear artifact to be exploded underground. How to verify it's not a bomb? "A guy with an instrumented hammer walks up to it," says Poggio. "He says a prayer, then hits it." Actually the prayer is for ceremonial purposes. "If a device can stand being transported all around," says Lager, "it can stand a hammer blow." Furthermore, if it is a peaceful device it has to be able to stand being put down a hole and having tons of dirt poured on top of it.

Poggio and Lager stress that the method is applicable not only to the analysis of acoustical data, but to many kinds of physical characteristics that can have a waveform nature: pressure, acceleration, electric field, electric current, charge density, etc. Poggio cites the possibility of using it to analyze the radar signal returned from a flying object. You can then refer to "something in your library and say that this is a MIG 25 and not an F 4."

"The breadth and scope of the applications since the development of the 'moving-window' scheme suggest a broad range of further applications as the technique is perfected and its capabilities become better known," reads an article in an internal Livermore publication. Indeed, one wonders what a forensic pathologist might have done with an analysis of the bell sounds from the tower at Fenchurch St. Peter. Of course Dorothy Sayers never had forensic pathologists. She preferred old-fashioned coroners aided by sextons with shovels. Still, suppose she had been more scientific, and suppose the poor victim had been tapped on the head with a hammer, as was once done to deceased popes to make sure they were really dead. □