Acoustics • Shock • Vibration • Signal Processing **October 2001 Newsletter**

G'Day Mate!

I express special thanks to Dave Corben and Mats Lago for submitting materials for this newsletter.

Dave Corben is an engineer for the Philips Centre for Industrial Technology in The Netherlands. He submitted a Matlab code for SRS analysis. His code is posted at:

Matlab Code

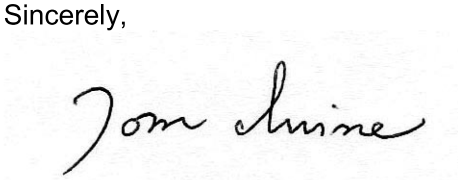
Mats Lago is an engineer for Saab Ericsson Space in Goteborg, Sweden. He provided a scanned copy of an SRS paper by Robert Morse. The paper is posted at:

Morse SRS Paper

Again, I encourage readers to submit articles and other items of interest.

Also for this month's issue, I have included two articles. The first discusses the Kursk submarine Tragedy. The second describes an ingenious method for measuring the weight of astronauts orbiting the Earth.

Sincerely,



Tom Irvine
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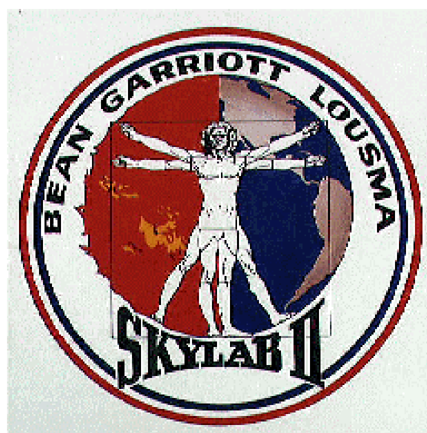

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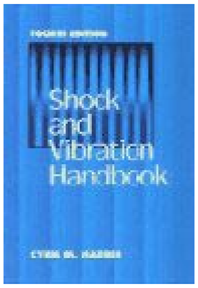

Cyril M. Harris, Shock and Vibration Handbook

Price: $150.00
Availability: Usually ships within 24 hours

Hardcover - 1456 pages 4th edition (December 11, 1995)
McGraw-Hill Professional Publishing

Order Cyril M. Harris, Shock and Vibration Handbook from Amazon

Description:

Widely used as the most authoritative and comprehensive reference work on shock and vibration in print, this mechanical engineering classic has undergone major revisions. This edition now devotes more pages to the latest vibration instrumentation based on computer-chip technology, innovative computer techniques for solving practical vibration problems, and the new measurement techniques currently being encountered by engineers.

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Introduction	Condition Monitoring of Machinery	Vibration Isolators
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The Kursk Submarine Tragedy: A Shock & Vibration Perspective
By Tom Irvine

INTRODUCTION

The Kursk was a nuclear-powered cruise missile attack submarine. It was the tenth of the Oscar II class of submarines. It was also one of Russia's largest and most capable submarines. The Kursk even had a double hull that consisted of an inner pressure hull and an outer hydrodynamic hull. The double hull was designed to provide improved survivability against conventional torpedoes.

The Kursk and approximately 30 other Russian naval vessels held a training exercise in the summer of 2000 above the Arctic Circle in the Barents Sea. Tragically, the Kursk experienced a catastrophe on August 12, 2000, which resulted in the death of the entire crew of 118 sailors aboard. Most crewmembers are presumed to have died instantly. Twenty-three men survived, however, at least four hours afterward in a sealed compartment, according to a scrawled message by Lieutenant Captain Dmitri Kolesnikov.

The disaster left the Kursk stranded on the sea floor, beneath 100 meters of icy water. Several rescue attempts were made to save possible survivors, but these attempts were hindered by poor visibility and 4-meter high waves. Finally, Mikhail Motsak, chief of staff of the Russian Northern Fleet, pronounced the Kursk flooded and all the sailors dead on August 21.

In the weeks following this crisis, Russian navy commander Vladimir Kuroyodev and Deputy Prime Minister Ilya Klebanov both stated that the accident had been caused by a collision, thus attempting to blame the United States or one of its allies. U.S. Department of Defense officials, however, claimed that there was "no indication that a U.S. vessel was involved in this accident."

In the midst of the debate, the Russian leaders failed to explained how the alleged attacking vessel sailed away undamaged and undetected, while the doubled-hull Kursk quickly sank to the seabed.

The debate continued for several months. In the mean time, seismologists were evaluating data that would eventually settle the argument.

The principal investigators were

University of Arizona Seismologists:

Keith D. Koper
Terry C. Wallace

Los Alamos Seismologists:

Steven R. Taylor
Hans E. Hartse

The foursome published a definitive article, "Forensic Seismology and the Sinking of the Kursk." The article was published in EOS, the weekly newspaper of the American Geophysical Union, on January 4, 2001. .

Specifically, the team presented data in this article that proved the Kursk Sank due to an internal explosion, instead of an external collision.

SOURCE ANALYSIS

Terry Wallace's computers at the University of Arizona simultaneously monitor 500 seismic stations around the world via the Internet. As a forensic seismologist, Wallace is concerned with man-made events such as airplane crashes, industrial explosions, and nuclear tests.

Wallace first heard about the Kursk accident on August 14. He then began analyzing seismographic data from monitoring stations in Finland and Russia. The data clearly showed tremors. Natural seismic activity is rare in the Barents Sea, however.

Furthermore, Wallace noted that the tremor signals had arrived at the various seismic stations at different times because each was at a different distance from the source. Sample data is given in Figure 1. He was then able to pinpoint the tremor source using triangulation. The resulting source was exactly where the Kursk was reported disabled.

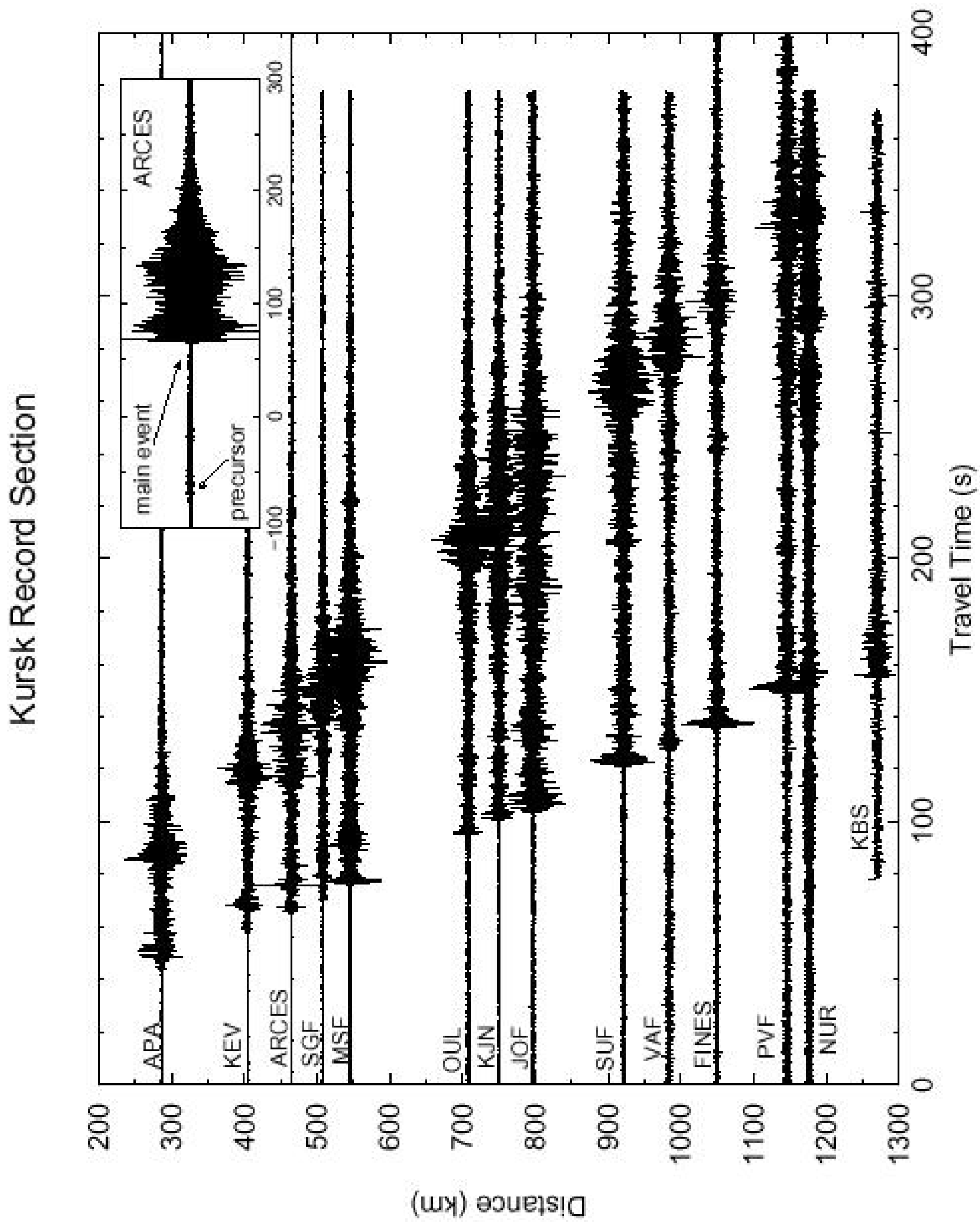


Figure 1. Vertical Component Record Section of the Main Kursk Event.

Each trace has been highpass filtered and normalized to a common scale.

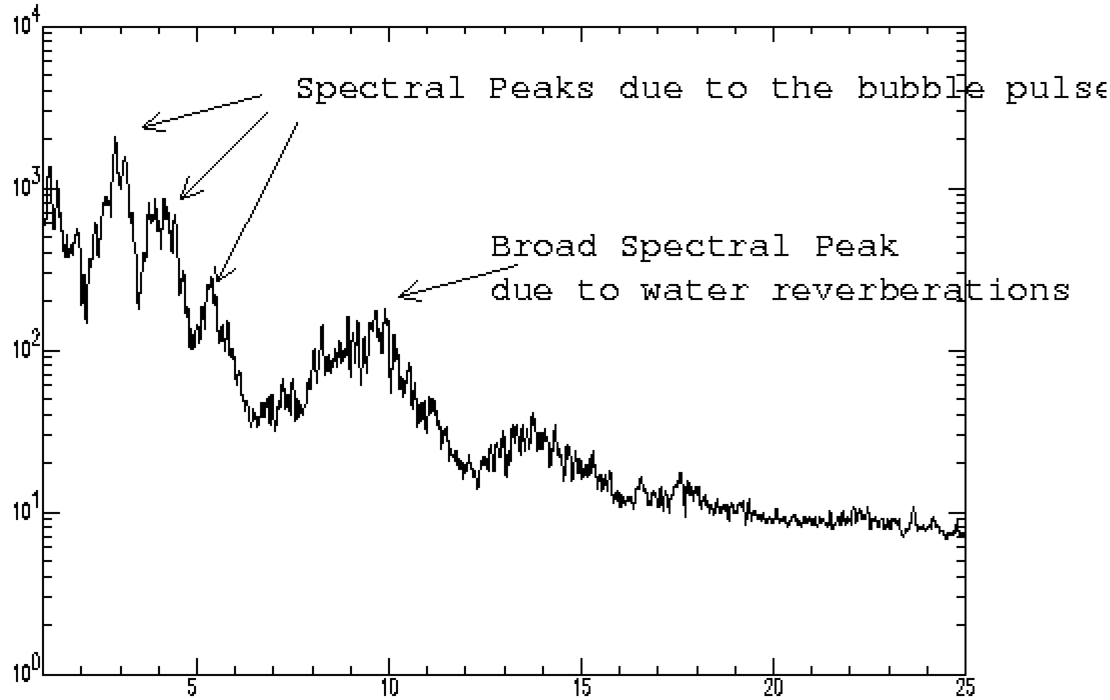


Figure 2. Spectral Function of the Main Tremor

The spectral data is taken from the IRIS station KEVO in Finland.

SPECTRAL ANALYSIS OF MAIN PULSE

Next, Wallace performed a spectral analysis of the main seismic event. The analysis revealed that the Kursk generated spectral peaks characteristics of a "bubble pulse," as shown in Figure 2.

A bubble pulse is generated when hot gases are created in an explosion. This bubble rises rapidly and oscillates. The oscillation depends on the size of the explosion and the depth of the detonation. Seismologists are well acquainted with bubble pulses from years of experience in offshore-oil prospecting and nuclear-bomb testing.

The spectral peaks in Figure 2 are due to the bubble pulse and water column reverberations, as indicated. The bubble pulse peaks are separated by 1.45 Hz.

The broad spectral peak at 9 Hz corresponds to water column reverberation. The equivalent period is 0.11 seconds. The speed of sound in salt water is approximately 1500 meters/sec. Thus, the distance per cycle is 165 meters. The half-cycle distance is 85 meters. This distance is similar to the report that the Kursk sunk to a depth of 100 meters.

Again, the spectral pattern in Figure 2 is clearly due to an explosion. This unique pattern rules out the possibility of collision or impact.

ANALYSIS OF PRECURSOR PULSE

Wallace also discovered a small, precursor pulse that occurred 135 seconds before the main tremor. The precursor pulse was only

1/250 th as large as the main pulse. The two events, however, had nearly identical seismic signatures, thus indicating similar source mechanisms.

MAGNITUDE

Wallace assigned the following local magnitudes to the shock pulses.

Precursor: ML = 2.2
Main Event: ML = 4.2

The precursor event released energy equivalent to about 150 kg of TNT.

The main event released energy equivalent to about 4500 kg of TNT and was recorded at distances of up to 5000 km.

FURTHER EVIDENCE

Divers discovered that the Kursk sank with its periscope up, which gives strong evidence that the catastrophic series of events began near the water surface.

Furthermore, there are reports that the Kursk radioed for permission to fire a torpedo a few minutes before the first explosion.

No distress signal from the submarine was ever received, indicating that the radio center in the third compartment must have been destroyed instantly.

SCENARIO

Thus the Kursk was apparently at the sea surface when a torpedo warhead, or its volatile liquid propellant, exploded inside the submarine. Fire then quickly spread through the front section of the submarine. The hull was breached by the explosion, and water poured in.

The Kursk then sank to the seafloor during the 135-second period following the first event. The second, larger explosion may have been triggered by impact with the seafloor. Alternatively, the main explosion may have been caused as fire from the initial explosion reached missiles stored on the submarine.

The main event is consistent with the explosion of four to eight SS-N-19 ship-to-ship missiles, or one cruise missile tipped with a conventional high explosive warhead.

CONCLUSION

The body of data, particularly Wallace's spectral data in Figure 2, provides compelling evidence that a series of two explosions destroyed the Kursk.

The Russian naval commission in charge of investigating the disaster is waiting until the Kursk is raised to issue its final report. The recovery has been delayed, however, due to lack of funding.

Update as of October 15, 2001

The Kursk has now been raised and is being towed to a port near Murmansk. Caution is being taken due to concern over the vessel's nuclear reactors.

Once the Kursk is docked, officials will carefully remove the remains of the crew.

For further information, please visit:

http://www.geo.arizona.edu/geophysics/faculty/wallace/RUSSIANSUB/

How Astronauts use Vibration to Measure their "Weight" in Space

By Tom Irvine

INTRODUCTION

Scientists have always been concerned how the environment of space would affect astronauts' health. Biomedical research continues to be a high priority for space missions.

The purpose of this article is to first discuss the physics and physiology of "apparent weightlessness."

A particular problem is that "true weight" cannot be measured by a bathroom scale in space. Scientists, however, have devised an ingenious vibration device which provides an indirect solution for this measurement.

PHYSIOLOGY

A space vehicle orbiting the Earth continues in a state of constant free fall. This free fall is the source of the "apparent weightlessness" which astronauts experience in orbit.

Some of the very real effects of this "apparent weightlessness" include:

1. Loss of bone mass (similar to osteoporosis)
2. Reduced volume of red blood cells
3. Giddy, light-headed feeling
4. Space sickness with nausea and vomiting
5. Decrease of heart size
6. Nasal congestion
7. Muscle weakness

Note that the heart does not have to work as hard in space to pump blood. On the other hand, the heart must work hard on the ground because it must pump blood against the force of gravity.

Similarly, muscles do not need to work as hard in space due to the apparent lack of gravity.

Astronauts can maintain healthy muscles in space by exercising. For example, astronauts aboard MIR exercised using a treadmill and stationary bike.

Another effect that astronauts may experience is possible tissue damage from radiation. There is no atmosphere or ozone layer to protect the astronauts from this radiation.

PHYSICS

There are two types of weight:

1. True Weight
2. Apparent Weight

"True weight" results from Newton's law of gravitation.

The force F between any two particles having masses m_1 and m_2 separated by a distance r is an attraction acting along the line joining the particles. This force has the magnitude

$$F = \frac{G\, m_1\, m_2}{r^2}$$

where G is a universal constant having the same value for all pairs of particles.

$$G = 6.6720 \; [10^{-11}] \; \frac{N\, m^2}{kg^2}$$

Reference: Halliday & Resnick, Physics Parts 1 & 2, Wiley, New York, 1978.

A particle can be a planet, a star, a person standing on a planet, or any physical object whatsoever.

The formula for the true weight W can be derived from the formula:

$$W = m\, g$$

where m is the object's mass and g is the acceleration of gravity.

The acceleration of gravity at the Earth's surface is about 9.81 meters/sec^2. Again, the "true weight" does not depend on an object's state of rest or motion.

"Apparent weight" is essentially the weight measured by placing the object on a bathroom weight scale. Imagine that you were standing on a weight scale inside an elevator. The scale would show that your "apparent weight" increases as the elevator accelerates upward. On the other hand, your "apparent weight" would decrease as the elevator accelerates downward.

An object in a free-fall has "zero apparent weight."

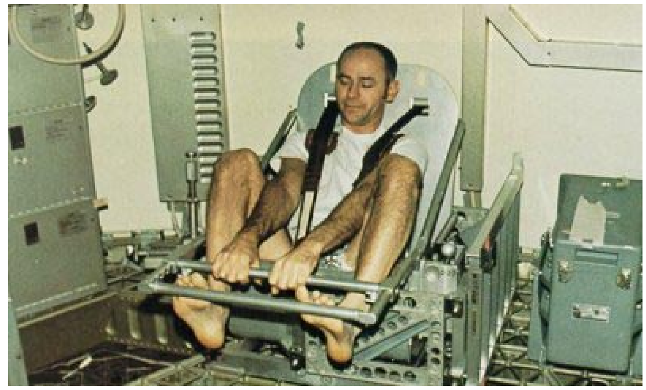
Astronauts experience "apparent weightlessness" as their space station orbits the Earth. Nevertheless, this "apparent" condition produces very real physiological effects, such as loss of bone mass, as previously mentioned.

MASS MEASUREMENT PROCEDURE

Again, space station astronauts cannot use a bathroom scale to measure their weight. William Pogue, an astronaut on the Skylab space station, wrote that this space station had a special chair that swung back and forth on springs. This device was called the body mass measurement device (BMMD). It was also know as the M172 chair.

Measuring body mass in the M172 chair was not a simple matter. The human body is not rigid, and any internal motion--even breathing--could affect the oscillation of the chair. After emptying their pockets, astronauts would climb into the chair, always wearing a suit which had been weighed before the flight. They would then be strapped in rigidly, brace their feet against a bar at the front of the chair, grab hold of another such bar with their hands, hold their breath and then release the seat by pushing a trigger on the hand bar.

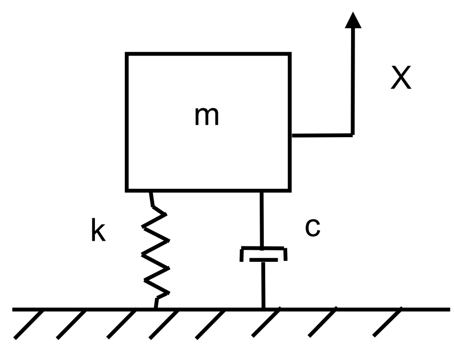
The motion of the oscillating mass was tracked electronically, typically over three back-and-forth oscillations, and from this the instrument derived the oscillation period T. Theory predicted that T would be proportional to the square root of the oscillating mass. This was confirmed by calibrations in space, using previously weighed objects. The calibration data suggested that such mass measurements were accurate within 0.1%, when carefully performed.



Astronaut Alan Bean "weighs" himself on the body mass measuring device, aboard Skylab.

VIBRATION THEORY

The device can be modeled as a single-degree-freedom-system as shown in the following figure.



m = mass
k = spring stiffness
c = damping coefficient
X = displacement

The damping coefficient can be neglected, however, by assuming that the device was lightly damped. The undamped, natural frequency ω_n for a spring-mass system is

$$\omega_n = \sqrt{\frac{k}{m}}$$

The period T for a spring mass-system is

$$T = 2\pi \sqrt{\frac{m}{k}}$$

The period is the time required for one complete cycle of back-and-forth motion.

Mass can thus be calculated as

$$m = \frac{k\,T^2}{4\pi^2}$$

The total mass of the astronaut and chair system could thus be calculated from the period of oscillation. The astronaut's mass was the total mass minus the chair mass and minus the clothing mass.

The astronaut's "true weight" could then be calculated by multiplying mass by the gravitational acceleration.

CONCLUSION

The body mass measurement device was successfully used to measure the astronauts' weight on the Skylab space station by means of vibrational period.

Similar devices have been used on the MIR space station, the space shuttle, and on the International Space Station.