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PRECISE MONITORING

Geometrical stability in the measurement set-up is crucial for the world's biggest and most precise ring laser gyroscope. Clear arguments for using "Zerodur" as the base material.

Wettzell Fundamental Research Station, June 7, 2000. The crane gradually lowers a huge "Zerodur" glass ceramic disk millimeter by millimeter into the partially completed underground laboratory. The giant disk, 4.25 meters in diameter, 25 centimeters thick and weighing 10 tonnes, forms the heart of the "G" ring laser, the largest instrument of its type in the world. After several hours, the "Zerodur" block finally comes to rest eight meters under the surface of the Earth. There it is positioned on a concrete foundation which itself sits on a solid rock foundation 12 meters below. "It's a really strange feeling", says Dr. Ulrich Schreiber of Munich Technical University, "to see the whole experiment hanging in the balance from the hook of a crane." The experiment in the Wettzell geodesic observatory has in fact been commissioned jointly by the Bundesamt für Kartographie und Geodäsie (BKG or Federal Cartography and Geodetics Bureau) of Frankfurt/Main and the Forschungseinrichtung Satellitengeodäsie (FESG or Satellite Geodetics Research Institute) of Munich Technical University. Its ambitious goal is to demonstrate short-term variations in the Earth's rotation.

Successful measuring tests have been carried out in New Zealand using a prototype ring laser made at Zeiss and incorporating "Zerodur".

Alternative to radio telescopes

Procedures used previously are based on determining the rotation of the Earth using radio telescopes and reference objects such as distant radio stars or quasars. The spatially fixed reference system of the quasars can be linked on the basis of these measurements with reference systems on the Earth as it rotates – important information for satellite-supported navigation systems such as the "Global Positioning System" (GPS) for example. However, these measurements are relatively costly and they can only be carried out in conjunction with several radio telescopes at different locations on the Earth. That is why independent alternative procedures are important.

Ring lasers are such an alternative – although not of the type that is used in compass systems for airplanes. The sensitivity of these laser gyroscopes needs to be increased by a factor of more than a thousand. The realization of the measurement principle and the technical requirements were investigated in a project study carried out jointly by the BKG, the Munich TU and the University of Canterbury, New Zealand. For this purpose a one-square meter prototype was produced by Carl Zeiss using a single piece of "Zerodur" made by Schott. This instrument was installed and tested in 1997 in an underground laboratory in New Zealand.

Test run confirms practicability

The research team in New Zealand already had the necessary infrastructure capable of handling the tests for which the "Zerodur" block was shipped. The success of the tests justified the effort: "As we already knew, the Sagnac effect was too small with this ring laser to demonstrate variations in the length of the day. We were, however, able to obtain the information we had hoped for about the effects of

OF THE EARTH'S ROTATION

amplification of the laser light, variations in the ambient temperature and pressure conditions on the experiment". In addition to this, however, the ring laser also gave us some indication of further possible uses. Dr. Schreiber: "With the ring laser we were able to "see" the disastrous earthquake that occurred last year in Turkey – in spite of the fact that it occurred on the opposite side of the globe. These ring laser seismograms do not look the same as conventional seismological measurements – perhaps there is an opportunity here for inter-disciplinary research that will provide new information about earthquakes.

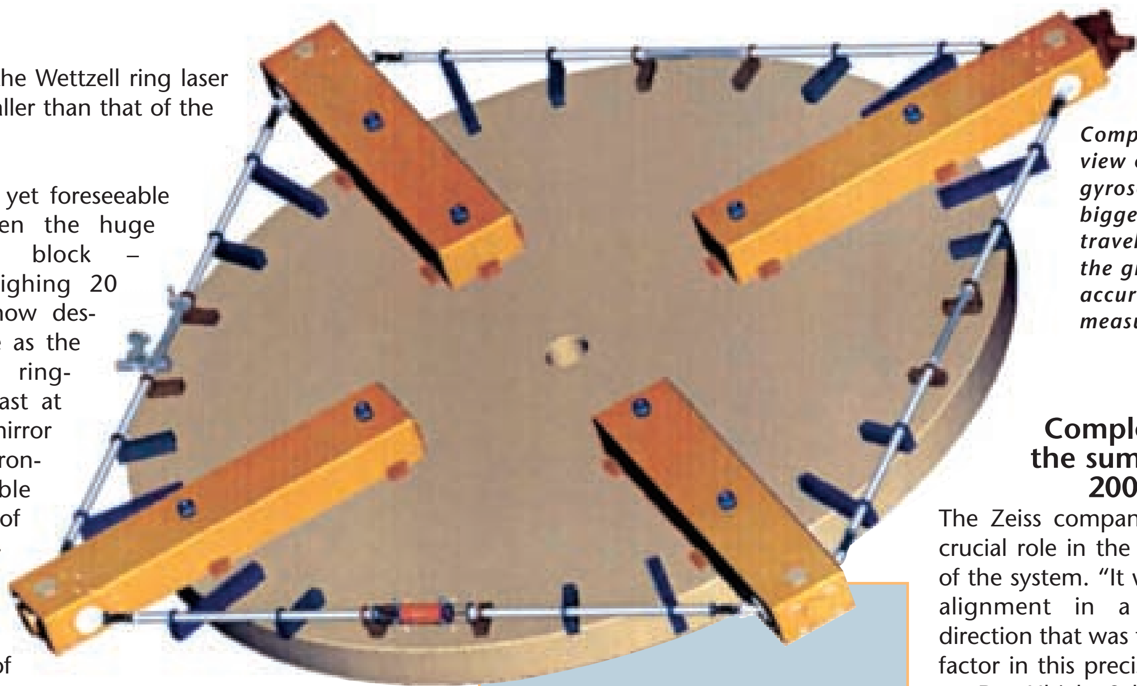
At the center of the world's largest ring laser gyroscope there is a 4.25 meter diameter "Zerodur" disk. The material was specially heat treated to achieve a thermal expansion of only 60 millionths of a millimeter per Kelvin.

"Zerodur" is the material of choice

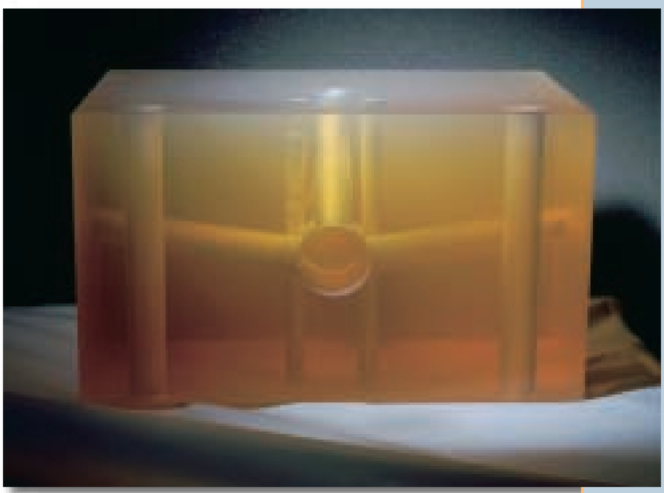
At this time the decision had already been made for an even bigger ring laser. In 1998 Carl Zeiss in Oberkochen received the green light from the BKG to build the large "G" ring laser – again using a "Zerodur" block made by Schott. But why was this material chosen? In order to demonstrate the minute differences in travel time of the laser beams, no changes can be tolerated in the actual measurement array and consequentially the travel time of the laser light. "Zerodur" with its extremely low thermal expansion appeared to us to be the most likely base material amongst several choices to offer the possibility of success", argues Dr. Ulrich Schreiber.

However, the thermal expansion of the 4.25 meter diameter monolith for the Wettzell ring laser had to be smaller than that of the prototype.

That was not yet foreseeable in 1992 when the huge glass-ceramic block – originally weighing 20 tonnes and now destined to serve as the core of the ring-laser – was cast at Schott as a mirror blank for astronomy. Double the amount of care and preparation was, therefore, required at every stage of manufacture. First the raw disk was cut into two halves – a procedure which took a week to complete – with continuous quality monitoring as it was converted to its present form. To reduce its thermal expansion to a fifth of the previous "Zerodur" value, the blank was subjected to further heat treatment – known as post-ceramization – which took three months. As a result of this treatment, the block now only expands 60 nanometers per degree Kelvin temperature variation.



Computer-drawn view of the laser gyroscope: the bigger the circuit traveled by the rays, the greater the accuracy of the measurements.



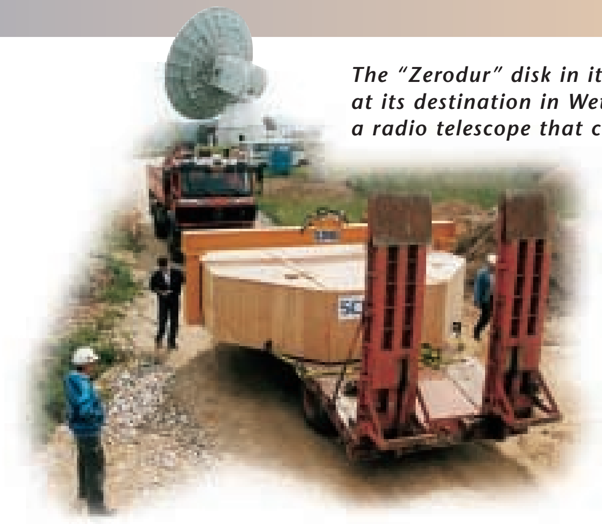
A block of "Zerodur" used for test drillings. The holes are required to house laser equipment and the ray guidance system.

The Sagnac effect: laser gyroscope registers frequency differences

In a ring laser, several mirrors form a closed circuit or ring – also known as a resonator – around which the beams travel. This circuit, which is typically rectangular, is encased in a steel tube in which a helium and neon gas mixture is stimulated with high frequency radio waves to emit laser light of a certain wavelength. This laser light can now travel round the circuit in two opposite directions – one clockwise and the other anti-clockwise. When the array is stationary, the two laser beams traveling in opposite directions meet exactly at the point of origin in each case. When the array is rotating, however, because it is rotating as part of the rotation of the earth for example, one beam has a shorter distance to travel while the other has some distance to "catch up" to reach the point of origin. As a consequence of this, a minimal frequency difference occurs between the two directions of travel. This is called the Sagnac effect. The difference in travel time as a measurement of the rotation speed of the reference system is proportional to that of the surface enclosed in the ring laser – that is why the size of the ring laser is a crucial factor. With 16 square meters of surface traveled, the Wettzell ring laser is the largest and most accurate in the world.

Completion in the summer of 2001

The Zeiss company played a crucial role in the positioning of the system. "It was not the alignment in a particular direction that was the decisive factor in this precision work," as Dr. Ulrich Schreiber explains, "but the exact location point. In the final analysis, no distortion could be tolerated in the ring laser." For that would interfere with its



The "Zerodur" disk in its special packing arrives at its destination in Wettzell. In the background is a radio telescope that can also be used to measure the earth's rotation.

stability and put the success of the measurement into question. "After all, we are aiming to record frequency differences of a millionth of a Hertz out of a frequency of 300 Hertz. This is the frequency difference occurring with the normal variations in the Earth's rotation in the course of a day."

The glass-ceramic disk is now being equipped with four "Zerodur" bars onto which the stainless steel structure for the laser equipment and the beam guidance system manufactured by Zeiss will then be installed. Afterwards, the instrument will be enclosed in a pressure vessel and the whole underground laboratory in Wettzell will be thermally sealed – all measures designed to ensure a stable environment on a long-term basis. The "G" ring laser is scheduled to be completed in the summer of 2001. Up to this time Dr. Ulrich Schreiber does not expect to encounter any significant difficulties. The scientists will then proceed with caution, taking one step at a time until they achieve the resolution they are looking for – the finale. "The finest result", says Dr. Schreiber, "will be when variations within the course of a day finally become visible" ■

The 10 tonne glass-ceramic monolith is lowered onto the concrete base of the underground laboratory.

ROSAT: Methuselah among satellites

Germany's ROSAT X-ray satellite began operation on June 1, 1990. Its mirror system, built by Carl Zeiss, was only intended to operate for two to three years. Yet up to a few months ago it was still transmitting sensational pictures back to its ground station.

The optical system, which is used to discover the X-rays, is tubular in shape. Eight mirror shells, made from "Zerodur" glass-ceramic are combined to form a nested Wolter telescope. The outside surfaces of the mirrors were etched enabling them to withstand the mechanical stress at blast-off. Even before it was taken into service, the ROSAT mirror system was listed in the Guinness Book of Records as the world's smoothest mirror. This refers to both the surface of the mirror and also the way the mirror shells are aligned.

ROSAT has already made many new discoveries. "ROSAT delivered its most valuable pictures at the time when it should really have stopped working," says Professor Joachim Trümper of the Max Planck Institute for Extraterrestrial Physics in Garching. It has transmitted back to its ground station a map of the sky that never existed before.

ROSAT has discovered more than 100,000 X-ray sources that were previously unknown. Due to ROSAT it has been possible to identify traces of titanium 44 in an explosion cloud from a supernova – an element that has a very short lifespan by cosmic standards. Another spectacular result was the proof of X-ray emissions from "class L brown dwarfs" that were only discovered a few years ago.

ROSAT stopped operation a few months ago. Right up to the last, the optics delivered perfect and brilliant pictures. The satellite was replaced by the Chandra observatory that is also equipped with "Zerodur" mirror shells. The highly interesting results from ROSAT, however, will take some years to evaluate fully ■

Sandra Adams

Schott supplied eight cylindrical "Zerodur" mirror blanks in the 1980s for the mirror system of the successful ROSAT X-ray satellite.