1947 - 1997 A Half Century of Geodimeter

Provided for reprinting by Parson Advertising for Spectra Precision

It is now 50 years since the first successful experiments were made with a prototype instrument that, with its competitors, was to develop into a range of instruments that were to come to rule the lives of field surveyors. It might be dubbed *From Bergstrand to Bergstrand* since it was Dr. Bergstrand who was the prime mover 50 years ago and it is Model Bergstrand a new model of the Geodimeter that was launched in 1997 as a commemoration of the intial research.

Development of the Geodimeter, and its microwave equivalent the Tellurometer some 10 years later, would not have been possible without a reliable value for the velocity of light. Looking at distance measurement from the surveyor's point of view accuracies of a few centimetres (or 50 years ago an inch or two) was necessary for a new method or instrument to be viewed with any degree of favour.

One way of relating the velocity of light waves to distance is through the formula: *Velocity = Distance / Time or V = D/T*

At that time, the measurement of T was very good so the problem was really that of the effect of uncertainty in V on the distance D. Thus there was a direct relationship between D and V being that the proportional error in a resulting distance equated to the error in V.

For first order traversing the surveyor was often looking for 1 in 100 000 accuracy or better and as the velocity of light was approximately 300 000 km/s this equated to knowledge of the velocity to a few km/s. Was that a possibility, over 50 years ago, and even if it was, how might it be verified?

EARLY MEASURES OF VELOCITY

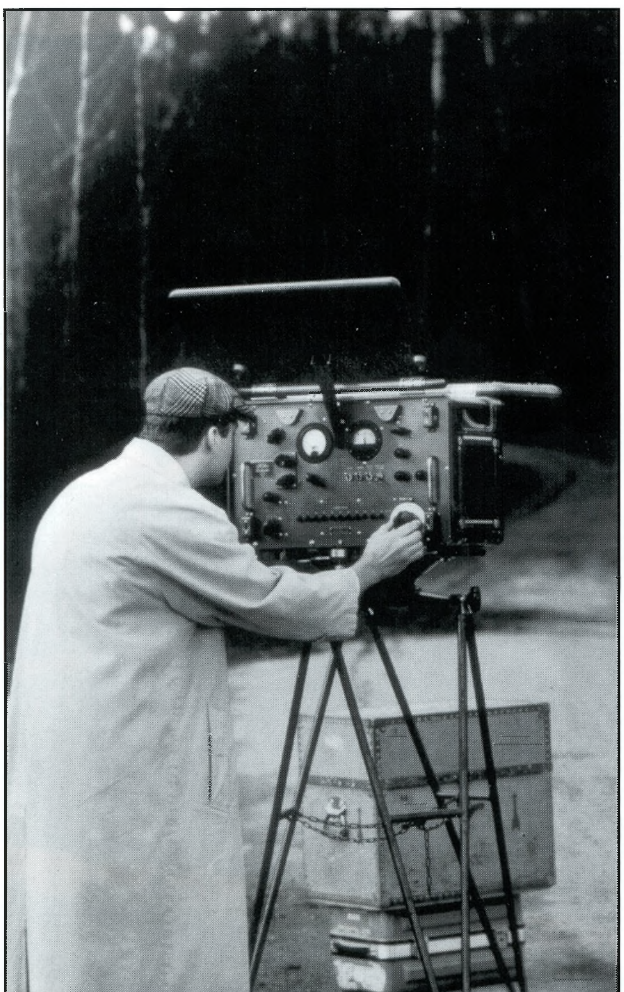
Knowledge of the fact that light travelled at a finite velocity can probably be credited to Olaüs Roemer (1644-1710). In 1671 l'Abbé Jean Picard visited the Danish island of Hven where Tycho Brahe had previously had an observatory. While there Picard made contact with Roemer and persuaded him to go to the Paris Observatory to further his scientific studies. Shortly after this (1676), Roemer was studying the movements of the moons of Jupiter and realised that the eclipses of any particular moon as it passed into Jupiter's shadow varied according to a pattern. He soon realised that this pattern related to the distance of the earth from Jupiter at any particular time. This, he correctly deduced, could

be explained if light had a finite velocity, and from the known facts about the earth and Jupiter at that time it was possible to derive an approximate value for that velocity. This he calculated, in modern parlance, as about 213 000 km/s.

Fifty years later the Reverend Bradley, Third Astronomer Royal, working at Kew Observatory, discovered the aberration of light or apparent motion of the stars due to the earth's orbital velocity. This information was again sufficient to determine a value for the velocity of light which he found to be 301 000 km/s. Thus, within that short space of time, and perhaps more by luck than judgement, the value was determined to within 1/2% of the presently accepted value. Further evaluations by various methods followed including the famous experiments of H. L. Fizeau, a French physicist, in 1849. Fizeau used a rotating cogwheel, which in essence was equivalent to both the light modulator and the phase meter, or synchronised shutter, of modern equipment. A pulse of light was transmitted to a distant mirror and on its return was interrupted by the rotating cogwheel. At a particular velocity of the wheel, the returning ray would be intercepted by the cogs and not be visible to an observer near the source. In effect the ray was modulated with the required frequency as it passed back through the cogs. From the parameters of a wheel with 720 cogs and eclipse at 12.6 revolutions per second, equivalent to the light travelling 17.266 km, the velocity of light was calculated as 313 000 km/s.

BERGSTRAND'S EXPERIMENTS

Many other determinations were made, but of particular note here was the work of Dr. Erik Bergstrand. Although it was Irving Wolff who effectively replaced the mechanical cogwheel with an electronic one, and should presumably be considered the inventor of EDM, it was Bergstrand who had been experimenting on the velocity of light for some years, and in 1941 conceived a 'blinking' light system. He effectively replaced the cogwheel of Fizeau with light pulses of known frequency and variable intensity projected over a line and returned to a receiving unit near the transmitter. The distance from the instrument to the reflector and back could then be expressed in terms of an integer and decimals of a cycle. Unlike Roemer or Bradley, however, it was now necessary to use distances known far more accurately than those to the planets and Bergstrand turned to lines of the Swedish triangulation. During the period 1947 - 1949 he made seven measurements with the prototype and first complete model of what was to become the Geodimeter.



These measurements were over lines up to 11 km long whose lengths were known to a few cms. From all his results he produced a weighted mean value of 299 793.1 ± 0.16 km/s. This must be put in the context of the value derived 30 years later of 299 792.46 km/s, which was the same as that adopted in 1983 in relation to the length of the metre. It will be seen how accurate Bergstrand's experiments were.

AN ACCEPTABLE VALUE

By the late 1940s the value that Bergstrand was getting for the velocity of light was considered to be good enough to turn his experiment around. Instead of using V = D/T to determine velocity he used D = V*T to determine distance.

In 1949 he experimented over a line of 20 km between two Swedish islands and one of 30 km between two points in Lapland. The first agreed with the triangulation value to 0.34 m and the second to 0.08 m or 1:59 000 and 1: 386 000 respectively. A new tool for the surveyor was up and running.

Early use of the Geodimeter in the United Kingdom came in 1953 when it was tested on the Ridgeway and Caithness baselines. [O. S. Professional Paper no. 19] Comparisons between the Geodimeter values (in metres) and those by catenary taping gave:

	Ridgeway	Caithness
Geodimeter	11 260.215m	24 828.071m
Catenary	11 260.189m	24 828.000m
Difference	+ 0.026m	+ 0.071m

Alternatively, using the mean results of the accepted observations at both bases, the value for the velocity of light was found as 299 792.3 km/s with an mse for a single observation of ± 0.5. Impressive agreements under any circumstances.

DR. SCHÖLDSTRÖM

In addition to Erik Bergstrand, a second personality who was heavily involved and should not be overlooked was Dr. Ragnar Schöldström.

Once the Geodimeter was establish we find him in 1955 using the Model 2 to determine the velocity of light as 299

792.4 ± 0.4 km/s. Schöldström's interdisciplinary knowledge was of specific importance to developments. As electronics developed so he and his team kept in step and moved from the long-range equipment into the, now more familiar, shorter-range models.
The joint work between these two in particular, coupled in the 1950s with that of Dr. Trevor Wadley for the Tellurometer, marked probably the most profound milestone in surveying practice since Snellius had developed the idea of triangulation in 1615.

PRINCIPLE OF THE GEODIMETER

The operating principle of the Geodimeter was the projection of a pulsating beam of light to a reflector and back to the instrument where a comparison was made between the transmitted and received light to measure the time for the light pulses to make the round trip. The light source used was a 6V, 5 amp projection lamp from which the light passed through the lens of a condenser to a Nicol prism where it was plane polarised. Then through a Kerr cell or fast electronic shutter between the plates of which was a crystal controlled high frequency voltage, and then to another Nicol prism. Then through more prisms and a parabolic mirror to a plane mirror at the far end of the line. On return, the signal passed through another mirror system to a photomultiplier tube. The signal was then amplified and fed to a galvanometer. Detailed descriptions of this can be found in various source materials but essentially the Geodimeter was a phase intensity comparator. The early use of a 'plane' mirror at the distant station was soon replaced by a spherical mirror system and then by prisms in various combinations sometimes up to a bank of 162 units. The 'plane' mirror was said to have a radius of curvature of about 20 km. The latest version of these is the active reflector designed to ensure that the signal is being reflected from a particular prism and not from any other reflective surface.
Light sources developed from tungsten filament lamps to mercury vapour lamps then to GaAs LEDs and HeNe lasers where the range can be 50 or 60 km.
For power sources a wide range of systems have been used with the latest version being the metal-hydride battery, which is said to be more environmentally friendly than its predecessors.

PROGRESS IN INSTRUMENTATION

The surveyor has always been interested not only in distances but angles as well. The early developments concentrated only on the former. The late 1970s saw the first step to overcome this situation. From dual systems, i.e. the distance unit separate from the angle-measuring unit, evolved the total station principle of integrated angle and distance devices. The first move was for distance units that would fit on top of a theodolite. The Geodimeter model 10 was limited in this configuration to about 1400 m as compared with some Geodimeter instruments capable of 60 km. This was not perceived a problem since the vast majority of distances required to be measured were shorter than that. It was only in specialist operations such as geodetic traversing that much longer lines were essential. In some instruments a difficulty was created in not being able to transit the telescope and allow readings on both faces.
However this was soon overcome with the development into a totally integrated system, i.e. one instrument containing both angle and distance measuring components, and the birth of the total station in 1975. Some systems had dual optics, others combined arrangements. By 1990 this had taken a further leap forward with the move from manual operation to servo-controlled.
Since 1990 and the Geodimeter System 4000 Series, there has been the possibility of operation from the target end as a remote system but this still remained essentially a total station. The Total Control System (TCS) is a series of instruments started in 1990 for use in industrial applications such as surface finishing and situations with non-contact requirements. From 1993 the geodolite series of instruments were designed, in response to market requirement, to be of low cost yet high quality. Auto Tracking Systems (ATS) came in 1996 for position monitoring and machine guidance based on the Model 4000 Series.
For all models there is a range of accessories to aid communication between instrument and target (Unicom); easy alignment of the target (Tracklight); automatic aiming after initial rough alignment (Autolock); data recording devices (Geodat) and numerous software packages. Certainly all not even considered a remote possibility by Bergstrand 50 years ago.
Specific reference must be made of the latest Model of Geodimeter, introduced in 1997, since it is named after Erik Bergstrand as the Model Bergstrand. It has a 4 speed servo drive with a range of 3500 m to one prism with distance accuracy of ± (1 mm + 1 ppm), and angular accuracy of 1" (3 cc). The internal memory takes 15 000 points and has 15 software programs.

INTRODUCING GPS

In recent years yet another new step has been taken with the production of Geotracer GPS units. Geotronics did not enter this satellite surveying market until it felt that the achievable accuracies with GPS were approaching comparability with that of EDM and total stations. The most recent development has been the Integrated Surveying system where the total station and GPS speak the same language and hence complement one another.

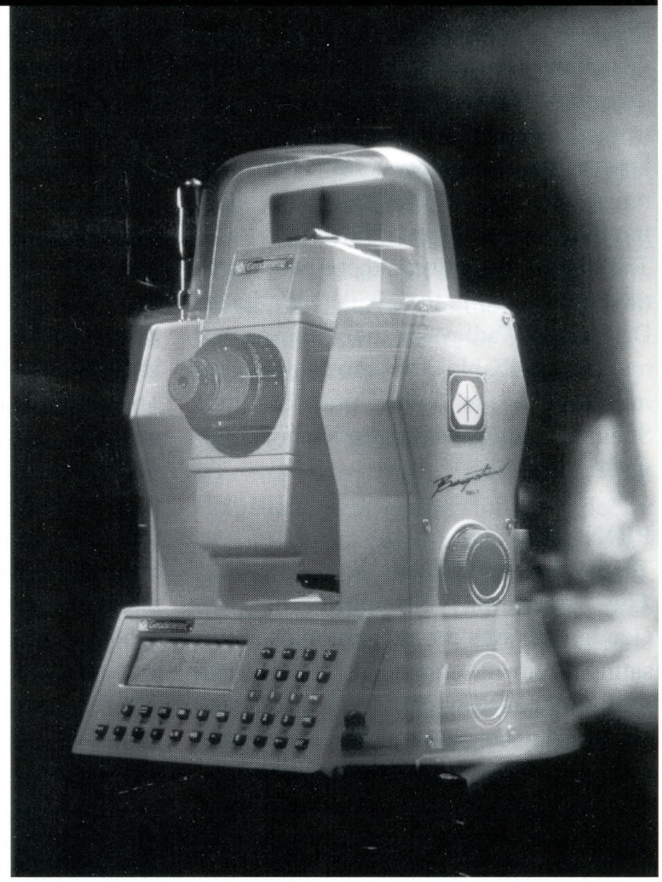
SUMMARY

In summary there has been the distance only measuring unit; the distance unit mounted on the angle measuring devices which became the integrated unit of the total station with its many variations including servo operation; and now the use of satellites for positioning.
What does the future hold? No doubt under wraps in the factory is the next generation of equipment. Dare one still call it surveying equipment when it is

likely to be even more general-purpose than GPS and yet further away from what even 30 years ago, let alone 50, were the traditional tools of the map-maker, the EDM, theodolite and maybe the steel band or linen tape. Surveying methodology and equipment has come very far in the last 50 years from the initial efforts of Dr. Bergstrand and Dr. Schöldström to the servo models and GPS of today. Geotronics, having introduced this key element to the market, has kept its position at the forefront of the technological developments that have continued to amaze the users yet make them ever more efficient without sacrificing accuracy.

Is it becoming too much of a routine operation and too far removed from the labours and difficulties that surveyors endured years ago? Gone is the need to occupy only hill tops or towers, gone are the laborious computations with log tables or mechanical calculator, gone are the instruments that the operator had a chance to repair if they were damaged. In are GPS stations wherever required, button pressing instruments, computer programs and automatic plotting. Modern surveyors do not know what they are missing - what was routine in the days of Dr. Erik Bergstrand!

This article is based on Geodimeter 1947-1997 J.R. Smith 3rd edition. Published by Geotronics, Sweden, 1997.
It was provided by the advertising agency for Spectra Precision, formerly Geodimeter, as a press release commemorating the fiftieth anniversary of the technology.



REMARKABLE RYERSON! 50 YEARS

LOOKING FOR A CAREER?

Consider geomatics engineering in the civil engineering program at Ryerson Polytechnic University. After the first two years of basic sciences, mathematics and introductory courses in civil engineering, students may select to continue in the civil engineering option or to enter the geomatics engineering option. Both lead to a Bachelor of Engineering degree. Ryerson is the only university in Ontario that offers this career path, which leads to registration as an Ontario Land Surveyor or as a Professional Engineer or both. For additional information tap into Ryerson's website at ***www.ryerson.ca***. Individual counselling can be arranged by calling ***(416) 979-5345***.