EDM PANEL ON INSTRUMENTS AND ATMOSPHERICAL CORRECTIONS

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D.G. Currie, A.H. Dodson, K. Poder

I. Brook: The aim of this session is to discuss EDM instruments which do not require the normal type of refraction corrections. The Georan is such an instrument and there are, of course, others, often still at the prototype stage, which also utilize two-colour techniques. I think we can even stretch us to including the Mekometer ME 3000 in this instrument category even though it is a single-colour instrument. We in Sweden use Mekometer equipment; and only have a theoretical knowledge of two-colour systems. Very few instruments seem to advance beyond the prototype stage and I think it is a question of nonprogress in many ways. We have read about many interesting developments such as dispersion studies done by Prilepin, Bender-Owen, Wood and Thompson. In the early 70's the National Bureau of Standards in Colorado produced a prototype two-colour instrument. The problem at that time was the size of the components and difficulties associated with suitable blue light sources. The equipment was not field equipment. At the 1974 Stockholm symposium a paper was presented by Hugget and Slater, where they described the equipment they were working on. I have been told that their instrument the Terrameter will in fact be produced commercially. We had two papers prepared by Bradsell and Shipley on the Georan 1 and the Georan 2, and were told that the instruments would be on the market within a few months after the Stockholm symposium, but as far as I know the instrument is not yet available. At the Land Survey of Sweden we have a ME 3000, and my experience of the instrument is not wholly positive. We have seen progress in developing better light sources, which can be used in practical field equipment. But we have seen also a change in the economic climate and escalating costs. The cost of a two-colour instrument today is of the order of a quarter of a million dollars. I think we should discuss to what extent we require and can afford two-colour equipment as well as the problems associated with calibrating and checking it. Dr Currie, what are your impressions of developments in this field?

D.G. Currie: From recent discussions it would appear, that instruments are being produced for the U S government. It is clear that the size and type of the market will determine prices and what manufacturers

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would aim for, as far as requirements are concerned. My impression was that it was not clearly defined, if the potential market was for ten units or one hundred units over the next few years. And that is something that will clearly affect prices, and it would seem to me that these kind of discussions will be valuable for potential manufacturers. I am not familiar with the details of what Hugget is planning, but that kind of information will be a very large factor in what would appear on the market. Another aspect is the question of when one needs one tenth of a millimeter and where one is going to be able to make use of such data.

I. Brook: I think Dr Dodson could comment on practical applications and requirements in this field. He has worked on deformation research. The question is do we need one millimeter, half a millimeter or a hundredth of a millimeter?

A.H. Dodson: On the shorter ranges instruments there is first of all the practical question of whether the two-colour instruments can solve the refraction problem because of the small amount of dispersion that is available. I think we have to look at what sort of accuracy we are aiming at. At the moment we can obtain 1-3 millimeter accuracy fairly easily in small engineering networks. This involves, however, a lot of theodolite work, and if we get more accurate EDM instruments we can cut out a lot of angular observations. But I think the problem of refraction, as far as engineering size work is concerned, is mainly what we have been discussing during the previous few days, that is, the vertical refraction problem. I do not think elimination of refraction in EDM instruments is so important to us, unless people are looking for higher accuracies than we at the moment think are necessary in the horizontal plane. The Mekometer we know was launched as being a 1 or 2 ppm instrument. My experience and Brook's experiences are that it is not that accurate. You can get differential measurements which are certainly that accurate, but the absolute accuracy is not as good. Do we need some further development along the lines of the Mekometer in order to produce the 1 ppm instrument without going to two colours? I think two-colour is out of the question for the short range instruments. But there is another aspect to this discussion. What sort of accuracy are we looking for at this shorter range? And should we be looking to improve the instruments or the techniques for eliminating the errors mathematically? Should we be looking in the latter direction rather than trying to improve instruments further, which undoubtedly is a very expensive business these days?

K. Poder: Up to now we have been speaking about the short ranges. If we consider long lines in the range from 40 to 80 km, then undoubtedly an 0.1 ppm instrument, which is technically feasible, with two colours should give you an accuracy of 4 to 8 mm. But then, of course, the geodetic large-scale community would have to deal with variation in time of the coordinated stations. This is one negative aspect. Then you have the curvature problems. This term will in most cases reach a magnitude of up to 0.5 m when you get up to these ranges. This means that the curvature, and here you will call it a large scale curvature, will possibly be the limiting factor for two-colour instruments on long ranges where it is very tempting to use them to get rid of the primary effect of the refraction. You are then back to the classical problem in all distance measurements, namely your metric unit will curve. You may hope to correct it slightly statistically, but the fact remains that for long ranges the main problem will be one of curvature effects. If you go to shorter ranges - here I am speaking as a geodesist interested in that scale of magnitude - then you could make networks with elements of 2 to 10 km. Most experiments, and also theory, indicates that there will be no need for two-colour instruments. The already well established techniques will certainly give you an accuracy of at least 1 ppm. There is one point more, namely the problem of the index error. Most instruments have troubles in the region from 1 mm to 1-2 cm, and I am putting the provocative question: what are you going to do with this index error? I was told that it was only a matter of proper technology, and I would, therefore, like some of the two-colour instrument makers just to join the teams making one-colour instruments and have them produce a more stable and smaller index correction.

T.J. Kukkamäki: I think that with Mekometers we get somewhat better accuracy than 1 ppm at distances of between some hundred meters and one kilometer. Even without two colours it is not difficult to determine the effect of the refraction when the lightbeam is going close to the ground. These kinds of measurements are, of course, very important for engineering and geophysical work. But then for these longer distances between 40 and 70 km it is not so easy to put the thermometers in the beam path. But with the two-colour method it should be easier to get an accuracy of 1 ppm or even better. And as regards curvature - my theory is not too strong - but I think it should be possible to determine from two-colour results the curvature with sufficient accuracy to compute the necessary corrections. Then one might ask why we need this high accuracies on these 40 km distances. We need such accuracies very urgently in areas of crustal movement.

P.V. Angus-Leppan: To me the Mekometer seems to be a slightly mixed up instrument. It has extremely high specifications and I think that the accuracy, specified, can be achieved, but only if one uses it as a normal instrument, that is applying an atmospheric correction. On the long range instruments, my feeling is that we will not have problems with curvature. In fact, the rather elegant equation set up by Moritz will solve that, even with a fairly crude model, even if the curvature is changing along the path. The model is obviously not accurate enough to give you the first velocity correction, but second velocity in the curvature correction can be worked out to sufficient accuracy with atmospheric models. What I think we could do constructively, and perhaps this conference could think about is: if we could draw up a series of specifications for an instrument, so that everybody would be satisfied with one instrument. Then we wouldn't get the various manufacturers competing with each other, each producing a small number of expensive units.

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L. Hradilek: I agree with professor Kukkamäki. The use of accurate instrumentations for the determinations of the earth's crustal movements is of very great importance. Such movements are of the magnitude of 5 mm a year and having such a precise ranging instrument we won't need to measure vertical angles for estimating the movement of mountain peaks. When the distances are inclined about 20-30 degrees, the determination of elevation differences - from the geometrical standpoint - is better than by other methods. For this purpose it is very important to have this instrumentation.

J. Milewski: I think that the two-colour instrument represents the future only for measurement of distances up to about 50 km, because at these lengths a very accurate reduction of the optical path is correlated with the accuracy of the length. This is very difficult because of the generally limited knowledge of the geometrical path, as we can only model the real path from the averaging coefficients. If these reductions can be made then we can make accurate measurements with two-colour equipment. For studies of crustal movements over lines of 20-30 km the two-colour instruments will probably prove to be of great importance.

K. Poder: The only long range two-colour measurements I have heard of, where we really get out to 80 km, were made on Hawaii many years ago. And the blue laser was of the size of a middle size field haubitser. So technically it is very difficult for a two-colour instrument to reach such distances. There is another purely theoretical problem, namely when you have a long range you get a separation between the red and the blue, which means what you are aiming at you do not really get, because the two waves will propagate in different atmospheric layers. Speaking of measurements of short lines, you can either measure a long line as the sum of small elements, or you can try to observe it directly and observe the refractive index along the line. So what you do if you break it up, is to get the index distribution along the broken line. For the extra effort involved you can spread your observations over a larger time and get a better randomizing. At the Helsinki symposium, I was very happy that we supported the short range instrument (2-3 km) concept and wanted them to be improved. And I still think this is the correct approach.

T.J. Kukkamäki: I cannot agree. It is correct to measure these sections, which are individually very accurate. But there is a problem. How can we project these individual sections to the chord? We need very accurate break angles, which are hard to obtain. For instance, when we determined the 900 km long traverse through Finland, the individual sections were not difficult to determine with Geodimeters. The main problem was to determine the angles.

I. Brook: May I also comment, when Froome produced the Mekometer he was talking about 3 ppm. We have had the use of four Mekometers and we were looking for an accuracy of 1 ppm, but ran into problems. The first instrument had a 14 ppm frequency error. The second one had a 10 ppm frequency error. The third one did not work properly. And the fourth one we are testing now. One must, of course, accept frequency drift, as frequency checks must be part of an EDM routine. What worries us is frequency instability. I have been in touch with Kern and explained that we have difficulties because we cannot get an agreement with our measured interferometer lines. According to Kern, the inconsistency must depend on the interferometer. So we have borrowed a new interferometer and are checking the indoor calibration baseline again. But I think, if you speak to Alan Dodson, who has worked very much with Mekometers, he will tell you that he is of the same impression as I am. I spoke to one of Kern's applications engineers when we had a one day symposium on the ME 3000, and his reaction was that we are not really sensible people, we geodesists, when we talk about absolute measurements, because it is not possible to measure an absolute distance with any instrument. With the Mekometer one should not at all discuss measuring absolute distances, you should only talk about measuring differences. So Kern themselves do not appear wholly to share your opinion about an absolute accuracy of 1 ppm.

T.J. Kukkamäki: When we purchased our Mekometer we calibrated it very carefully against our calibration line. The length of that calibration line cannot be absolute, not at all, but its accuracy of 0.1 ppm is enough for the calibration of the Mekometer.

I. Brook: We have, in fact, calibrated the Mekometer on a 140 m baseline, and on a 50 m interferometrically measured baseline. We checked periodical errors. I am not quite sure how you at the Geodetic Institute check the modulation frequency. The instrument works with a very high frequency and to check it one needs relatively complicated electronic equipments. I would also like to comment on the calibration of two-colour instruments. How shall we calibrate these instruments? If we shall come down to 0.1 mm, we must have standards which are a power of ten better than the actual instrument.

T.J. Kukkamäki: We had standard frequencies and calibrated with those. But that was only the partial calibration. The total calibration was against the calibration line. And we have a calibration line of half a kilometer with the accuracy ±0.05 mm, that is 50 μm accuracy.

K. Poder: I would like to comment on the earlier discussion. The projection effect is such that for a typical line you will lose a maximum of about 10% of the accuracy on the projection. Normally, the loss will be only a few percent.

A.H. Dodson: I would like to come back to the Mekometer for a while. I agree with both professor Kukkamäki and Ian Brook. We found with certainly more than one Mekometer, that the variations of the instruments are quite large and at times quite alarming. With full calibration: electronic calibration, baseline calibration, periodic calibration, and meteorological data along the line, we can get 1 ppm accuracy over short lines. But it is not an ideal instrument, if you are looking for one to do away with refraction. The problems of calibration are also quite considerable and to get a calibration better than 0.5 ppm is certainly not easy. Frequency variations can be quite large and we found day to day variations. So you have to make the calibration immediately before the observations and then immediately afterwards. And there is another factor. I think that the cavity is the main problem with the Mekometer. Certainly it could have been placed in a 5 mm engineering instrument, which would have done away with the need for refraction corrections; but to put it in a 0.1 mm resolution instrument was, I think, unwise.

D.G. Currie: Concerning the remarks by Kukkamäki and Poder: Since there are going to be at least one and probably several of the two-colour devices, would it be worth suggesting a study of data from them, which could permit a quantative answer to most of the discussion, which to a certain extent have been intuitive. I am sure instrument constructors would be interested in such requirements as Angus-Leppan has said earlier.

H. Kahmen: In Karlsruhe we have used Mekometers for several years, and I think we have had the same experiences as professor Kukkamäki. We measured many engineering networks of about 6 or 7 hundred meters and when we determined the coordinates, the mean square errors were always less than 1 mm.

A.H. Dodson: We have also had similar experiences, but your values are a measure of the internal consistency of the instrument. We found a very good internal consistency over short periods, but the absolute accuracy - unless we carefully calibrate frequencies - can be much worse. Certainly a calibration on an accurate baseline will show if we get an accuracy of 1 ppm or not. But the absolute accuracy is much more difficult to determine. Professor Kukkamäki's baseline will give him an absolute measure against the Väisälä comparator, and he is getting a very good agreement there, but both in Brook's and my own case it does not agree with the laser interferometer, that is, different laser interferometers. So somewhere there is something wrong. Perhaps in Germany and Finland you get better Mekometers than those available to us.

T.J. Kukkamäki: Maybe you have not been careful enough when using your instruments?

A.H. Dodson: It is quite possible.

D.G. Currie: Did you say that you used your Mekometer to measure your baseline, or did you use your baseline to calibrate the frequency of the Mekometer?

T.J. Kukkamäki: We used our baseline to calibrate the Mekometer. At first we calibrated our Mekometer for periodical errors and the frequencies, but we considered this only as a partial calibration. We need some total calibration so that we can practically use our instrument. And when we got, with these different distances, consistent results, then we were satisfied. The accuracy was better than 1 ppm.

D.G. Currie: But are you not then doing with your absolute baselines the same as what they did with their electronic facilities? Are you not calibrating your baseline on your half kilometer and carrying that to the other network? If you adjust the measure, according to what your baseline was, are you not doing the same as they did by adjusting the Mekometer to what their laboratory frequency standard said?

T.J. Kukkamäki: Yes, yes.

J. Kakkuri: May I add a little to this contribution by professor Kukkamäki. This Mekometer was studied on the Nummela standard baseline. The length of the baseline is 864 m, and it is accurate to 1 to 15 millions. On the baseline there are shorter lines also, 24 m, 64 m, 216 m and so on, and those distances were measured with the Mekometer and the differences between Mekometer determinations and the real baseline distances were compared with each other. And the agreement was better than 1 to 2 millions and in some cases 1 to 4 millions.

D.G. Currie: So you say you did not need to calibrate the Mekometer?

H. Kahmen: In Karlsruhe we repeated the measurements during several periods of the year, and the differences between the absolute and the Mekometer results were not greater than the mean square errors of the coordinates. In Karlsruhe we have done much work in connection with calibrating the frequencies. We have developed a special instrument for calibrating the frequencies. But I must agree with you, that high quality coordinates can only be achieved after very accurate calibration of the frequencies, immediately before and immediately after the measuring periods.

I. Brook: The major part of the discussions have dealt with the Mekometer, due, I suppose, to the fact that it is an instrument that we have seen or used. But few of us have had an opportunity to see even a prototype two-colour equipment, although we are conversant with the theory of the construction. I would like to echo what Currie said: it would be very interesting if an evaluation of Hugget's or similar equipment could be carried out. And I think that in Europe we are very willing to assist in these studies. We know, that in Finland there are very high quality baselines of varying lengths. We must have some accepted reference standard if we are going to evaluate the equipment. I am sure that professor Kukkamäki is willing to make baseline facilities in Finland available for these evaluations. Is that not correct?

T.J. Kukkamäki: Before midsummer we had a meeting in Helsinki with the U S Defense Mapping Agency and it was agreed that they should come with their two-colour instrument to check it on the Nummela baseline and on the 22 km long baseline at Niinisalo. Whether it will be the Hugget instrument I am not sure.

SUMMARY OF THE DISCUSSION

1) Two-colour or three frequency EDM devices may be important at medium distances (up to 50 km) for several purposes, where high absolute accuracies are required. But they should be handy to use in the field and easy to calibrate.

2) Short range instruments for absolute measurements of the Mekometer type, are extremely valuable, but such instruments need further improvements as regards facilities for frequency control.

3) Instability in and the size of the index error of existing EDM equipments should be decreased as far as possible.

4) The alternatives a) sum of small legs, or b) direct total distance should be investigated as regards ultimate accuracy achievable.