STABILITY TESTING OF ANALYTICAL PLOTTERS

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Abstract

The paper describes results from empirical tests of the stability of analytical plotters. Several instruments, with linear encoders and with spindels, have been tested. Instrument coordinates of grids and of the fiducial marks on glass plates have been repetitively recorded over periods of one day and of several days. Results show instabilities of registered coordinates either due to measuring hardware or due to the electronic components of the system.

1. Introduction

1.1 General

Analytical plotters came into practice in 1980's. At the same time the first papers of tests and recommendations were given out concerning the precision and the general evaluation of the analytical plotters. The most used criterium of the precision of the hardware has been, and still is, the calibration with variable number of parameters done with grids. The manufacturers usually provide the customer with a program for this.

There are papers /1/,/2/,/3/ which describe some additional tests for final acceptance and evaluation of an analytical plotter, e.g. for the viewer servo positioning system, plotting table, viewing system, and software. But there has not been many studies on the stability of analytical plotters although both the short-period and the long-period stability have a great importance to the final accuracy of the output of the work. According to manufacturers analytical plotters are in a stabilized measuring condition after the first 15...30 minutes the power has been switched on.

1.2 Background of the testing

In 1984 we incidentally noticed at the Helsinki University of Technology (HUT) that our analytical plotter Kern DSR-1 was not working correctly. Sometimes the instrument made errors when moving automatically to points measured in the previous model and sometimes there suddenly appeared y-parallaxes. At first, we thought human failures in pointing or in stereoscopy were the reasons for those, but after some experiments we were convinced it was a question of something much more serious. The most striking point was that at the same time the instrument calibration showed really good results, mean errors being 1...2 um. By means of a series of repeated measurements we found out that it was more a question of instability than of anything else.

2. Stability testing

2.1 Principles of the tests

The stability testing was started in 1984. Since then seven test sets of one to two weeks have been carried out with our Kern DSR-1. In order to investigate the stability of analytical plotters in general, the other five instruments were taken with in 1986 - 1987. Their testing lasted one week each, that is five working days with different combinations of variables. Naturally, the test set period should have been longer in order to draw clearer conclusions of the results, but instruments in practice can hardly be taken off longer from their every day use.

In order to investigate the instabilities of analytical plotters a series of empirical tests were decided to carry out. The simple principle of the tests is the following. Raw instrument coordinates of several points are repetitively measured every half an hour over a time of one to three days, with different combinations of variables thought to have an affect to the instability. The idea of the testing was to observe the coordinates of each point of interest over the test set period and to follow how they are changing.

At first, the points we measured were crossings of high precision grid plates. But since there was some doubt that the plates were so heavy that they might move along with the movement of the photo carriers, we used glass photographic plates with four fiducial marks exposed on and used the fiducial marks for pointing.

In order to have a good precision each point was measured five times successively so that the measuring mark was automatically and randomly moved away from the previous location of pointing. After these five pointings the coordinates and the mean errors were computed. As a criterium for accepting and registering the mean of the five pointings, the standard deviation had to be less than 1.5 um.

The measurements were done both clockwise and anticlockwise in order to see if direction of movement had any affect to the results.

One test set consisted of individual tests lasting from one working day, that is 8 hours, to two or even three days. The coordinate measurements were done in every fifteen minutes during the first two hours after switching the power on and thereafter in every thirty minutes.

As in practical work the photo carriers are moving most of the time, it was decided to test if this had any influence on the results. So the photo carriers were either not moving at all between two successive measurement times, or moving automatically from a registered point to the following one, stopping there for two seconds and then moving to the next point and so on in a loop over the 30 minutes.

The DSR-1 has an operation panel with function buttons and a microprocessor P3 just in front of the instrument. The operation panel is of luminous material and gets very hot even to touch. To investigate if it had any influence to the stability, some tests were done with both the P3 and the operation panel switched off in HUT.

The room temperature was always recorded. Also during one week, the temperature of nine different spots inside the Kern DSR-1 were recorded with calibrated sensors. It was clearly seen that the temperature inside the instrument varied in time, but between different spots the difference at the same time was never more than 1.5 °C.

In short, the variables used in the tests were:
- measuring order of the points,
- duration of the test,
- movement of the photo carriers, and
- operation panel and P3 on or off (only in DSR-1).

2.2 Instruments used in the tests

We used the following instruments in the testing
- mostly Kern DSR-1 of the HUT,
- another Kern DSR-1 in Helsinki, Finland,
- Wild BC-2 in Tampere, Finland,
- Kern DSR-11B in Karlsruhe, FRG,
- a special version Kern DSR-11-18 (with linear encoders and large photo carriers) at the factory of Kern in Aarau, Switzerland, and
- Planicomp C130 in Stuttgart, FRG.

Unfortunately, some of the test series were not complete because of failures in the instrument or in the computer, but even then one could get an idea about the stability of the instrument. Also, it is to be noted that in these tests the operator was not always the same person, but the testing situation was tried to be made as similar as possible: mean error of the five pointings of one point less than 1.5 um, approximately same size of measuring mark as also of magnification.

3. Results

<u>General remarks</u>

In every tested instrument some kind of instability was to be found. There were changes in coordinates during the first hour as well as later on. When the changes are less than 2 um it can be seen as noise, but usually they were between two successive measuring times and over the whole day were much bigger, from 2 to 5 um and from 3 to 10 um, respectively.

Every instrument was behaving differently and therefor it would not be justified to compare the instruments directly with each other, and also because the testing period for each instrument was so short.

Generally can be said that the behavior of the instrument in four coordinate axes differ from each other. E.g. in one coordinate the maximum difference was about 3 um over the whole day while in the another one the difference was gradually increasing to a difference of about 10 um.

In the following the results are presented according to the most important factors found to effect the stability of analytical plotters.

Time

It is clearly seen that in most cases the analytical plotter is not stabilized in 15...30 minutes after switching the power on, like manufacturers promise. The biggest changes in coordinates usually take place during the first hour, and then they seem to settle down a bit, but not always. Even after six hours there can occur a big change that gradually goes on and on. Very often on the following morning, after power on in the night but photo carriers not moving, the coordinates are not usually the same as on the previous day. Changes can be of order of 3...7 um. In case the work is continued next day, one should remeasure some of the points of the previous day to see if the changes in coordinates can be accepted or not.

There seems to be a difference if the photo carriers have been moving continuosly or if they have stayed in one spot. The time needed in stabilizing the coordinates is different to each instrument, but generally speaking one should let the instrument 'warm up' and the photo carriers move at least 1...1,5 hours after switching the power on. And if the photo carriers have not been moving, one should wait for about 1,5...2 hours before starting to measure the coordinates. (Figure 1.)

Movement

In repeated tests with movement of photo carriers between measuring times, the behavior of the instrument was very similar in each axis and in different parts of the photo carrier. But when comparing those results to the ones when the photo carriers had been in one spot (not moving between the measurement times), the behavior of the coordinates was very much different. That is most likely due to the heating effect of the movement to the photo carriers or to the spindels. (Figures 2. and 3.)

The direction of moving along the axis does not seem to make any difference. Measuring clockwise and anticlockwise does not have any remarkable influence on the coordinates in any instrument type. (Figures 4. and 5.)

Temperature

The temperature is a big factor effecting the stability of analytical plotters. To give an example, the first results of the Kern DSR-1 at HUT in 1986 showed as big as 12 um differences in one of the coordinates between two successive measurement times and very often there were gradually crescent changes in the coordinates during the testing period. When in the maintenance insulation was made more efficient, new ventilators were installed, and electrical wires were changed, one could see a big improvement in the stability.

The effect of temperature is also to be found in the results of the tests with the P3. The changes are more even in different axes when the P3 is off than with the P3 on.

Further, when there were bigger changes in the room temperature, one could see a change in the coordinates also. But in most cases the room temperature changed only 1...2 °C during one day. Anyhow, that does not explain the changes of 5...7 um often only in one of the points.

Position of the measured points

Test results show that the changes in coordinates with time are non-linear and of unequal size depending upon the position of the measured points in the grid or glass plate. The heating effect should expand the plate evenly, like a scale factor, but that is not to be seen in the results, at least not clearly. (Figure 6 .)

In instruments with linear encoders the changes in coordinates seem to be less or more even than in instruments with spindels.

Hardware or electronic error

When we started making these tests with the DSR-1 in 1984, sometimes there happened 'big jumps', changes of from 10 to 100 um in one of the coordinates between two successive measurement times (time difference of 30 minutes). That is very difficult to explain otherwise than as error in measuring hardware or in the electronic components of the system. In the Kern DSR-1 tests lasting one day were made to see if there are pulses 'lost' when the photo carriers are moving. However, the results did not show it to happen. When testing the Zeiss Planicomp there also happened similar kind of effect without any change in the test situation.

4. Conclusions

We were surprised to see that the stabilities of analytical plotters are not what one could expect according to the results of calibrations or to the statements of the manufacturers and users. Especially, in practical work when measuring coordinates of new points or DTM-profiles, the stability is as important, if not even more important, than the precision of the instrument. It is not possible to detect errors of some micrometers in those works but naturally they are affecting the final accuracy.

The results given above are only the first results and a larger report will be published later. Also, it should be kept in mind that the graphs and the numbers are only examples from the large material of more than 100 tests. What should be emphasized is that based on these tests, it is still not easy to draw clear conclusions of the reasons of the found instabilities. Although several factors are taken into account, it is difficult to separate all the possible influences from each other. Much more difficult, if not impossible, it is to find a linear model to correct these instabilities. More tests also with new kind of factors should be taken into the testing program before one could clearly and explicitly define the model of the stability of an analytical plotter.

5. Acknowledgements

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6. References

/1/ Jaksic, Z. Evaluation of Functional and Structural Characteristics of Analytical Plotters. ISPRS Proceedings, Hamburg, 1980.

/2/ Makarovic, B. A System for Evaluation of Analytical Plotters. ISPRS Commission II WG 1 Report, Hamburg, 1980.

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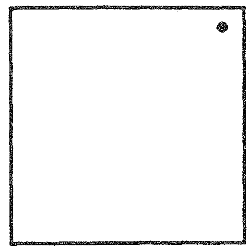
Appendix

In the following diagrams the differences in the four instrument coordinates of one point in the grid or glass plate are presented with time. The location of the point in the plate is drawn in the small picture. Also the maximum and mean differences in each axis are given.

	MAXIMUM DIFFERENCES			MEAN DIFFERENCES		
	1	2	3	1	2	3
dx left:	6.0	4.0	6.0	-3.0	1.7	-2.2
dx left:	5.0	3.0	5.0	-2.7	.9	-.8
dx right:	10.0	9.0	10.0	-5.0	1.7	.0
dx right:	9.0	5.0	4.0	-7.1	1.3	-2.5



1) after time 0
2) between 2 successive measurements
3) after 1/2 hour

COORDINATE DIFFERENCES (UM)

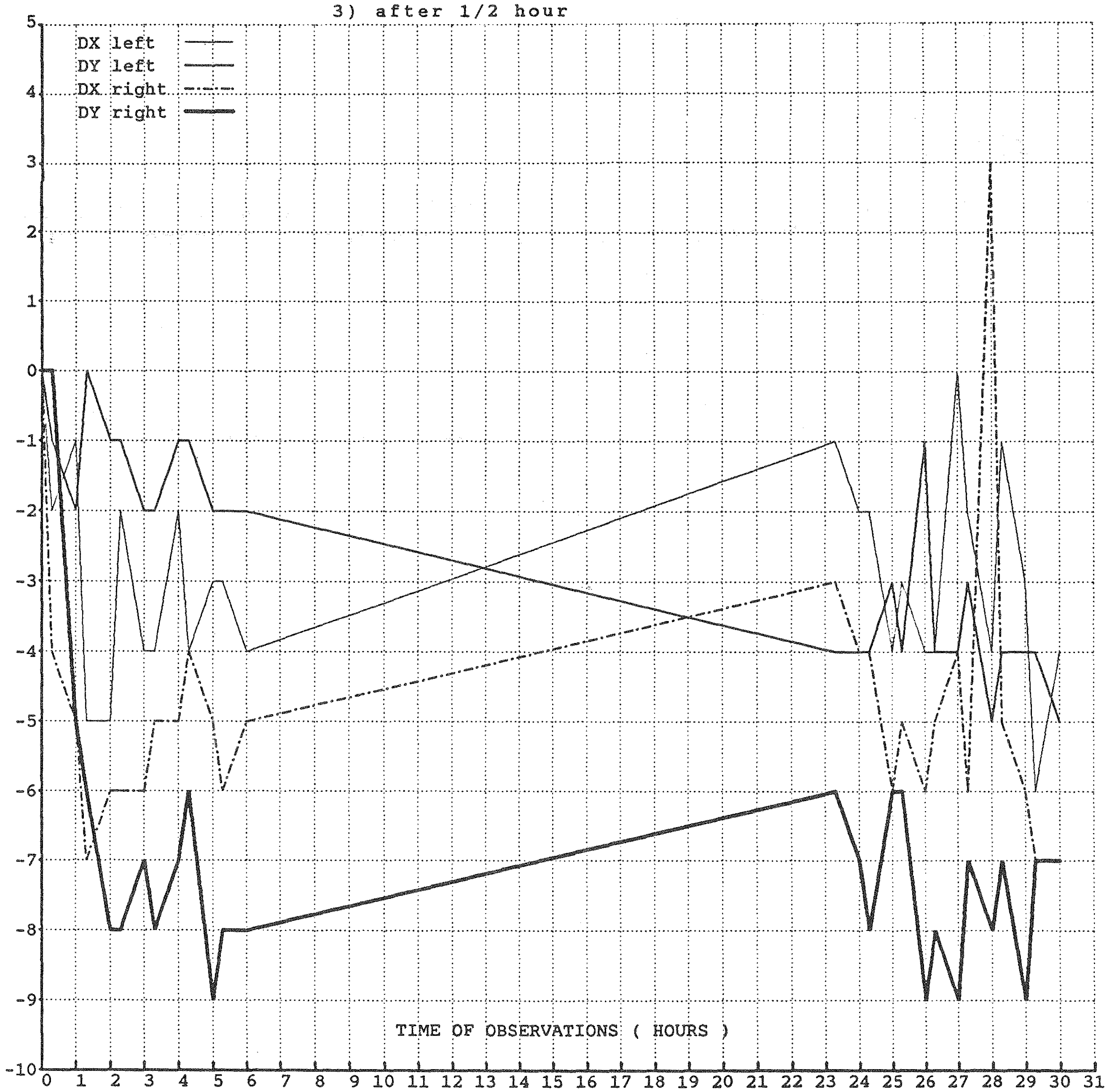
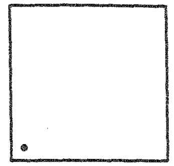


Figure 1. Example of changes in coordinates over a period of two days. DSR-1, measuring clockwise, photo carriers moving between measuring times, P3 on.

	MAXIMUM DIFFERENCES 1	2	3	MEAN DIFFERENCES 1	2	3
dx left:	8.0	4.0	4.0	6.4	1.1	2.5
dx left:	4.0	4.0	4.0	-1.9	1.4	1.1
dx right:	4.0	3.0	3.0	-2.9	.8	.1
dx right:	4.0	3.0	4.0	1.9	.8	3.1

1) after time 0
2) between 2 successive measurements
3) after 1/2 hour



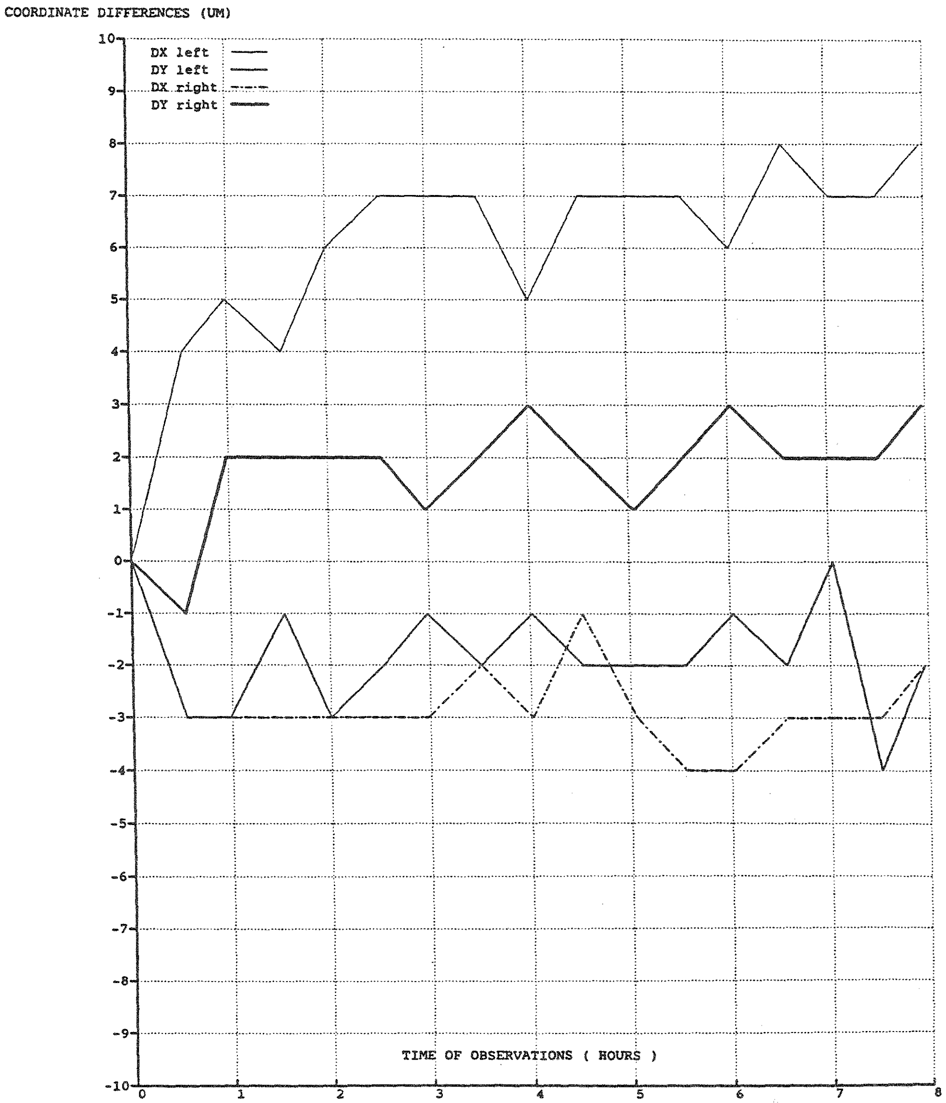
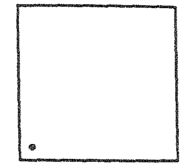


Figure 2. Example of results when the photo carriers had been moving between measuring times. BC-2, measuring anticlockwise.

	MAXIMUM DIFFERENCES 1	2	3	MEAN DIFFERENCES 1	2	3
dx left:	3.0	2.0	3.0	1.4	.9	1.5
dx left:	3.0	2.0	3.0	.4	1.1	.5
dx right:	3.0	1.0	3.0	-.6	.8	.5
dx right:	2.0	2.0	2.0	.7	.8	.7

1) after time 0
2) between 2 successive measurements
3) after 1/2 hour



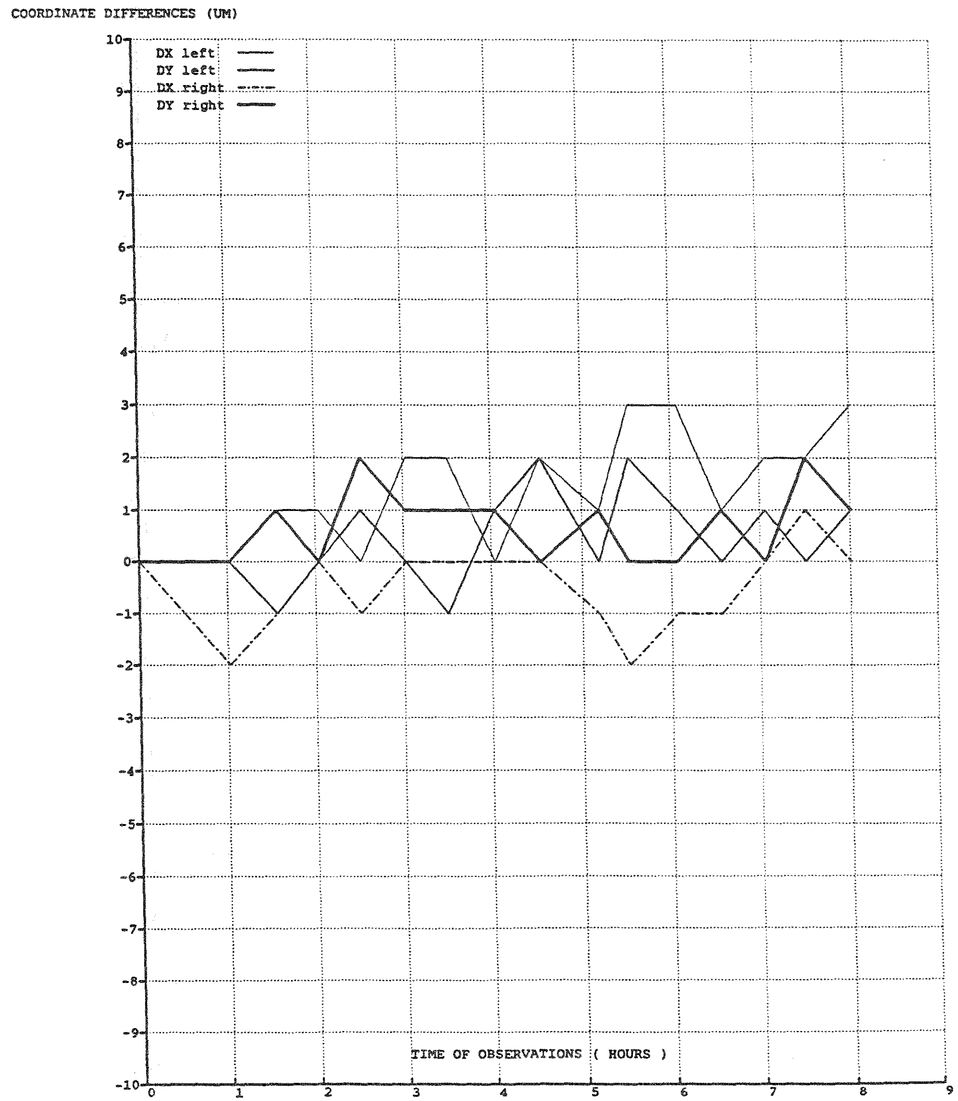
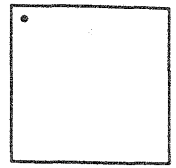


Figure 3. Example of results when the photo carriers had not been moving between measuring times. BC-2.

	MAXIMUM DIFFERENCES 1	2	3	MEAN DIFFERENCES 1	2	3
dx left:	8.4	4.3	3.5	6.7	1.6	.2
dx left:	3.6	3.0	3.3	-1.3	1.3	-1.8
dx right:	2.3	1.5	2.2	-1.1	.8	.6
dx right:	5.1	3.1	5.1	-.3	1.2	3.8

1) after time 0
2) between 2 successive measurements
3) after 1/2 hour



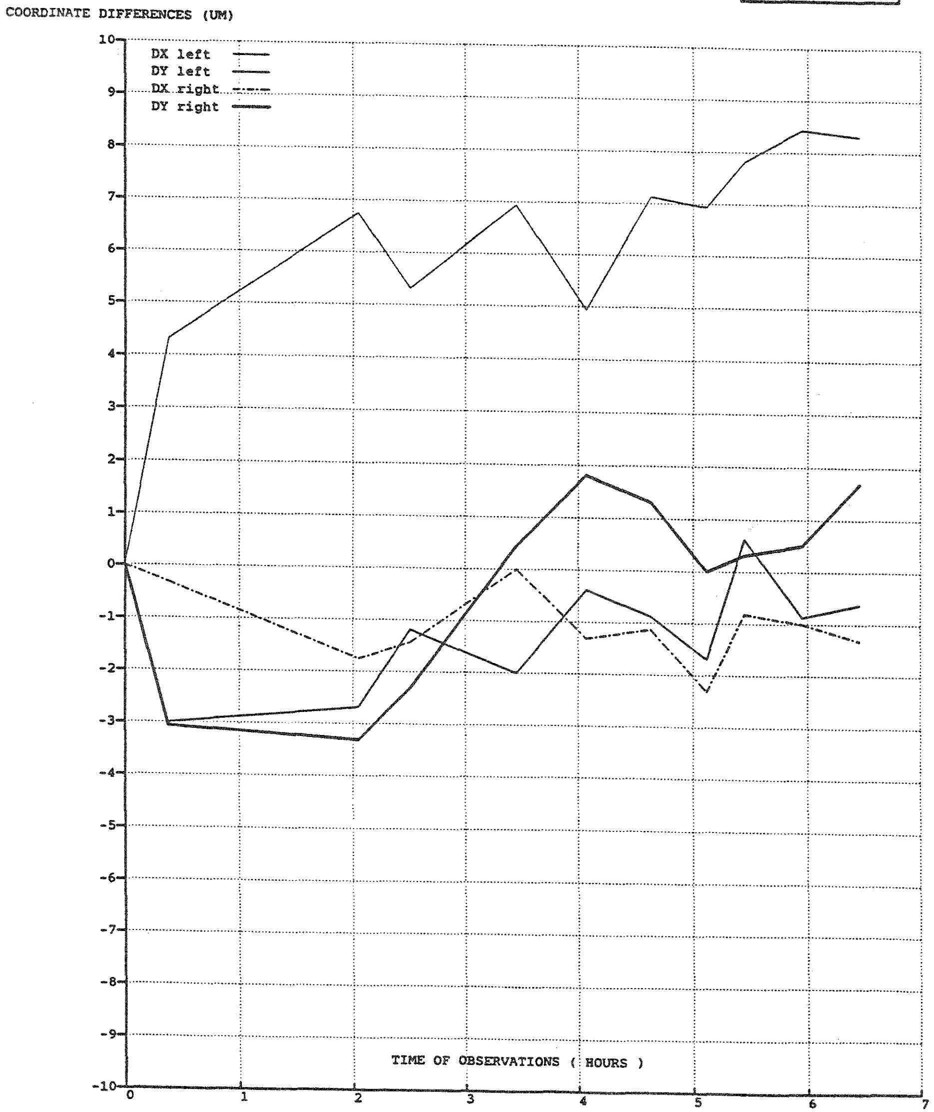
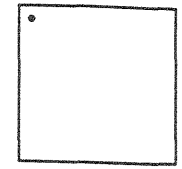


Figure 4. Example of results when the photo carriers had been moving clockwise. Planicomp C130.

	MAXIMUM DIFFERENCES 1	2	3	MEAN DIFFERENCES 1	2	3
dx left:	7.3	2.8	4.3	5.4	1.2	2.9
dx left:	3.0	3.4	3.0	-1.7	1.3	1.2
dx right:	3.3	2.4	3.3	.5	1.1	-1.3
dx right:	5.2	4.6	5.2	-.1	1.2	3.0

1) after time 0
2) between 2 successive measurements
3) after 1/2 hour



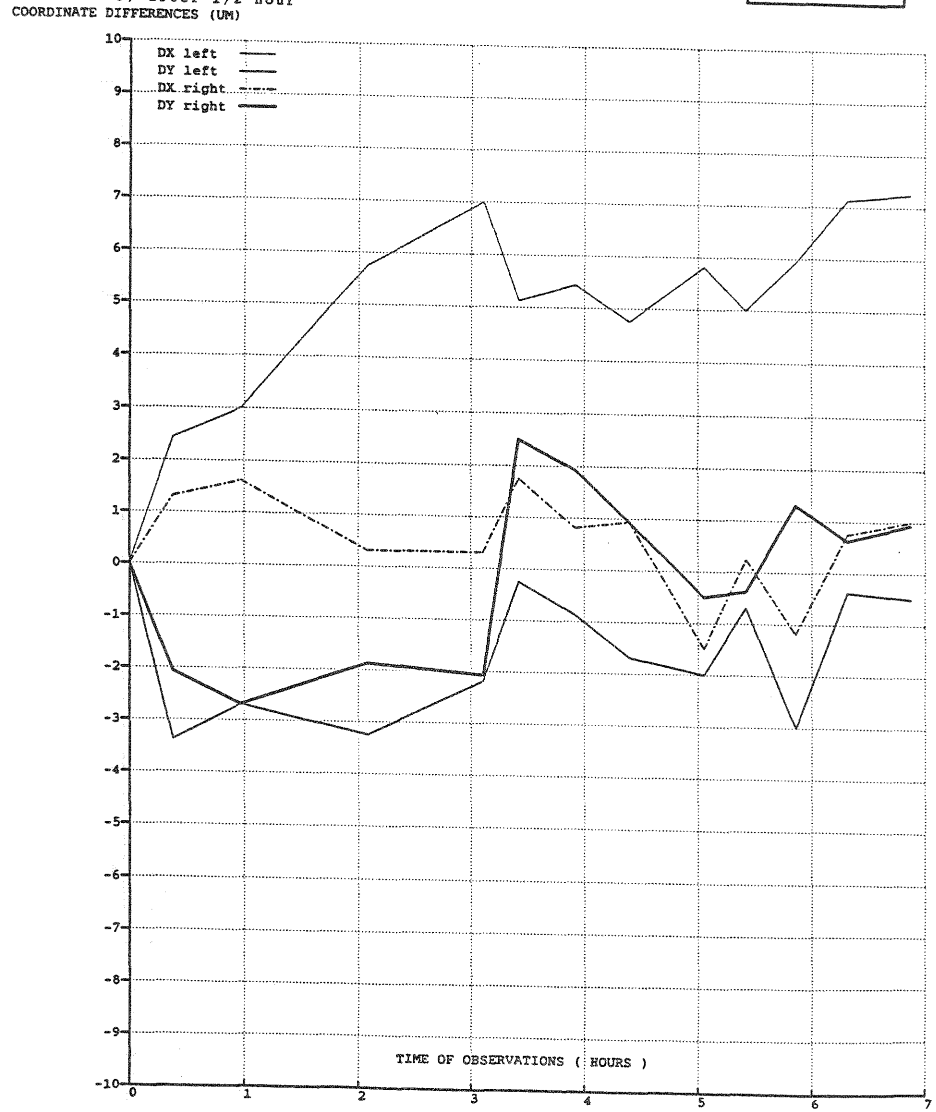


Figure 5. Example of results when the photo carriers had been moving anticlockwise. Planicomp C130.

In the following figure, the changes in the coordinates of four points in the plate are presented in the xy-plane. The big black spot shows the location of the first measurement of the day and the smaller black dot of the last.

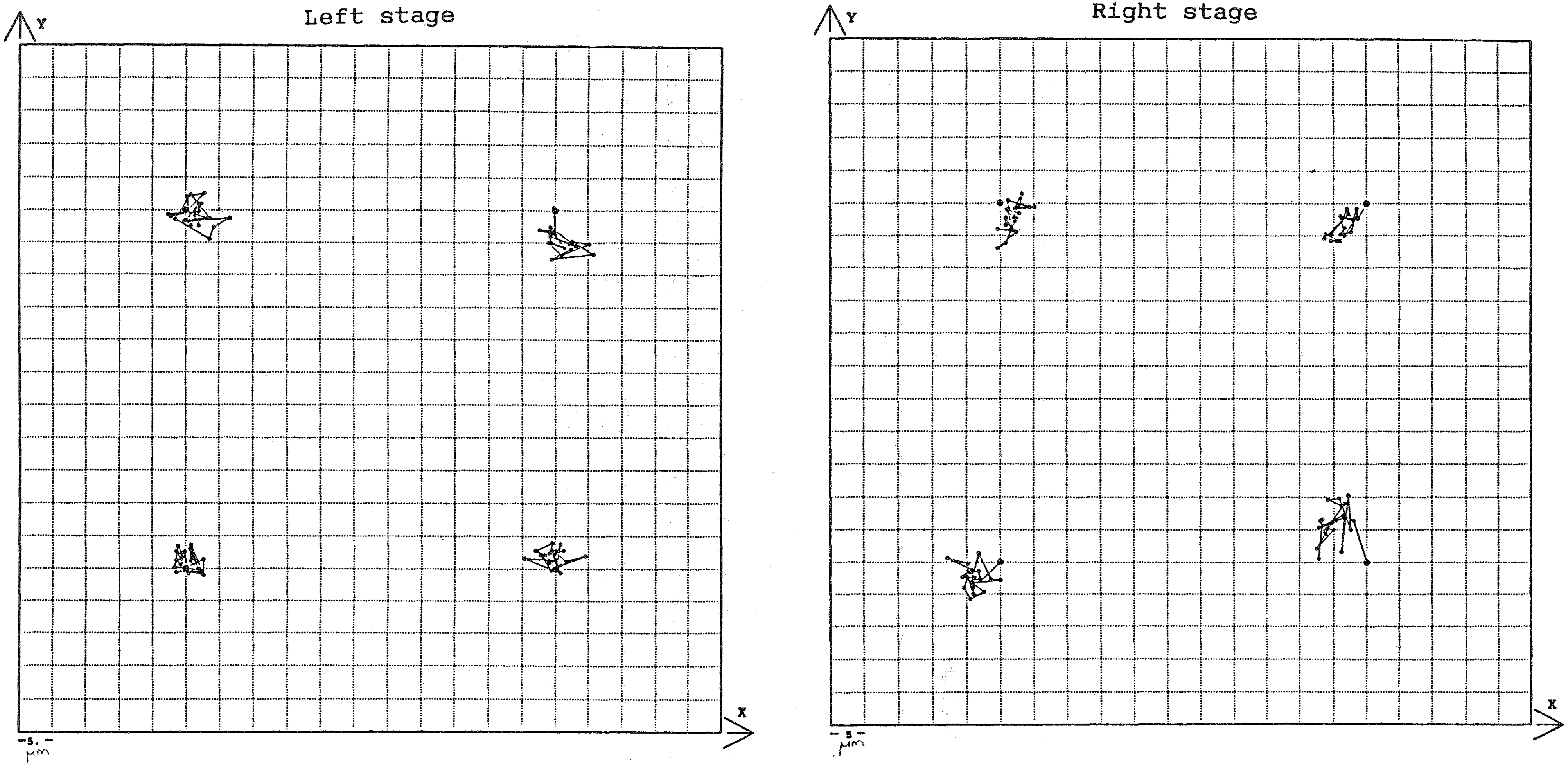


Figure 6. Example how the coordinates changed on the left and on the right stage during one test day. DSR-11, measuring clockwise, photo carriers moving between measuring times.