ALIGNMENT & GEODESY FOR THE ESRF PROJECT

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TABLE OF DIAGRAMS

INTRODUCTION

New generation accelerators and storage rings for synchrotron radiation require ever increasing precision of alignment, precision which moreover must be preserved over a maximum length of time.

The use of ever smaller beam dimensions, and ever narrower vacuum chambers leads the magnet positioning tolerances to be reduced to a minimum. Thus, unlike in the past, annual realignment due to progressive deterioration of the ground stability can no longer be envisaged. Permanent monitoring of the ground stability must be guaranteed and its effects compensated, as soon as significant deterioration is recorded. It is this viewpoint that has dictated the choices made by ESRF in the field of alignment and monitoring.

1. HOW DOES THE ESRF ALIGNMENT STAND WITH RESPECT TO OTHER MACHINES?

1.1 Dimensions of the machine

The Storage Ring of the ESRF project is a separate-function machine. The beam is bent by means of dipoles, and focussed by quadrupole magnets. The 608 magnetic components[1] are to be installed along a circumference of 844 metres in a lattice reproduced 32 times in a machine which measures 270 metres in diameter Although this machine does not fall into the category of giant accelerators, it could be interesting to compare it with the SPS machine at CERN in order to show the density of the elements to be installed. This machine is also a separate-function machine with 1000 magnetic components distributed along a circumference of 7 km, i.e. five times more components per kilometre for the ESRF machine.

1.2 Parameters to be measured on this machine

The geometric parameters used in the orbital correction calculations are adopted as the precision criteria during the installation of the accelerator components. These parameters are as follows :

dr - radial deviation at a given point of the Storage Rings's circumference
dh - vertical deviation in relation to the horizontal reference plane
dt - deviation in the tilt of the magnets

[1] ***64 dipoles, 320 quadrupoles and 224 sextupoles.***

The dh and dt parameters are measured in relation to a horizontal reference plane and the dt parameter is defined in a relative manner from one point to another, i.e. in this project, from one quadrupole to another. It is interesting to compare these positioning tolerances with those of the old ISR machine in CERN, whose objective was also to maintain beam stability until its utilization by the experimental scientists.

1.3 The objectives of the ESRF project.

Goals to be reached:

	CERN ISR[2] (radius 150 m) 1970		ESRF SR[3] (radius 135 m) 1990	
	Σt project	Σt results	Σt project	Σt expected
1) dt (mm)	0.15	0.08	0.10	0.08
2) dh (mm)	0.15	0.10	0.10	0.05 (with HLS)
3) dt (mrad)	0.2	0.02	0.2	0.02 (with HLS)

At a first glance, the goals of 1970 and those of 1990 do not seem to have evolved significantly. Indeed, the possibilities of high precision positioning have scarcely changed over the last twenty years within the range of measurements imposed by the accelerators (between approximately 0 and 50 metres). However, rapid developments within the field of electronics, the increasing reliability of computers and the development of automation today enable a number of solutions to be chosen, which ensure continuous monitoring of the machine in any given position, and the maintaining of this position to the same tolerances as those reached when the components were first installed.

If we consider the evolution of the ISR between October 1970 and August 1971, as shown in the graph below, we can see the deterioration of the magnetic components up to as much as 3 mm of amplitude in the vertical plane, over a period of 9 months on ground with a reputation for stability.

This graph enables us to highlight the difference between the two objectives from

[2] *CERN 76-19 by J. GERVAISE, Geodesy and Metrology at Cern, A source of economy for the SPS Programme.*

[3] *ESRF-SRILAT 88-06 by L. FARVAQUE and A. ROPERT, Storage Ring Magnets Tolerances.*

1970 and 1990. The well-considered challenge for storage ring projects is to permanently maintain the sensitive components of the machine within the tolerances achieved when these components were installed. This means realigning the components at monthly intervals or even less in a record length of time according to the forecasted ground movements.

The ground settlement measurements[4], that have been carried out over the last six months on two experimental buildings of the *Institut Laue Lungevin,* which mark the geographical limits of the ESRP project show a probable relative ground settlement near 0.6 mm/60 m/6 months. These results are quite comparable with those measured for the ISR machine at CERN: 3 mm/942 m/9 months.

Even if the ground under the ISR had a stabilization age of only two years, instead of four years for our example an extrapolation shows:

ISR	3 mm/942 m/9 months
ESRF	2.8 mm/844 m/9 months

2. WHICH SOLUTIONS FOR THE ESRF PROJECT?

2.1 Standard Solutions for Standard Problems

2.1.1 'First order' geodetic networks for the ESRF[5]

The objective of these networks is to position the various installations of the project, buildings and machines and above all to enable a connection to be established between the PINJ, SYTU, SRTU machines, transfer and beam lines.

There are precisely 3 networks at the present time:

a. External geodetic network, made up of about twenty points, its base is a regular octagon marked out over the Storage Ring Tunnel (diagram 2).

b. Internal geodetic network of the booster synchrotron, made up of a set of 48

[4] *Protocol Measurement ESRFIALGE 8903, First elements for refection upon the ground settlement on the ESRF site.*

[5] *MAC Grenoble, June 29-30 1988, Alignment methods for the ESRF.*

pillars or wall brackets laid out according to the booster synchrotron lattice (diagram 3).

c. Internal geodetic network of the Storage ring, made up of a set of 64 pillars or wall brackets laid out according to the Storage Ring module (diagram 4).

2.1.2 Standardization of the references and modular measurements.

Although the ESRF will be responsible for constructing the installations of the future, nothing can be gained by ignoring the innovations of the past. It is in this frame of mind that we have confirmed the choices made for previous projects (CERN, DESY, SLAC, ARGONNE) in the field of geodesic boring, essential for precision measurement (diagram 5 - 6), and in the division of the network into modules, well adapted to the instruments described below (diagram 7 - 8).

2.1.3 Instrumentation

In a previous pape[6], we report how we had hesitated between two instruments for measuring these networks. This dilemma of choice was solved by the results obtained on the interferometric base at CEFW[7], which were recently confirmed by calibration measurements on a reference base carried out using the DISTINVAR[8]. We have chosen the most recent distancemeter on the market: the DI2000 manufactured by the Swiss company WILD[9]. The R.M.S. expected on the ‘first order’ external network with this distancemeter is less than ±1 mm. Moreover, the pre-alignment installation of all of the components of the machine will be carried out with this instrument to ±1 mm, which should allow us to succeed in aligning the machine in onepass only.

As far as the measurement of the ‘first order’ internal networks and the alignment of the orbit is concerned, we will use the DISTINVAR (diagram 9), which is the only instrument capable of measuring distances of 0 to 50 metres with a precision less than 0.05 mm, and the ECARTOMETER (diagram 10), which is the only instrument capable of measuring alignment offsets of 0 to 50 cm with a precision of 0.05 mm. These two instruments have been developed at CERN over the last twenty years, and have been available for the last four in an automatic version driven by microcomputer, thus rendering them more reliable and less fragile in the

[6] *MAC Grenoble, June 29-30 1988, Alignment method for the ESRF.*

[7] *ESRFIALGE Report 8805, April 1988 WILD DI2000 DISTANCEMETER CALIBRATION*

[8] *Protocol Measurement ESRFIALGE 8906 February 1989, Base de reference INVAR*

[9] *This instrument will be demonstrated on the occasion of the visit to the ESRF02 building.*

What are the qualities of this instrument and why does it perform so well in comparison with its predecessors?

The limitations of systems available in October 1987:

a. Use of a contact sensor

b. Thermal problems connected to the high level of water used in the majority of the systems.

c. Condensation problems connected to the presence of water along the sight of the sensor in the existing systems.

Improvements made on the October 87 system by the ESRF prototype: (diagram 12)

a. The use of a non-contact sensor with a large integration surface avoids a whole number of problems caused by contact sensors (moistening, alteration of the touch point, meniscus effect, fluid vibration).

b. The use of an inexpensive and easy-to-use conducting fluid. The problem connected to its high factor of thermal dilation (2 **µm/°/cm)** is minimised by the use of a low level of water (3 cm) and a measurement of the vessel temperature to an accuracy of **0.1°C.** This gives us a thermal error of less than 0.6 **µm.** This is possible because our machine is horizontal.

c. The presence of a radiator (small Rower transistor enabling the temperature of the sensor to be increased by 1°C in relation to the water).

What are the advantages of this instrument?

a. Replaces the encoders in the jacks with a quasi-similar precision, with a slight delay in the information due to the inertia of the system (less than 2 minutes),

b. The fact that it is installed in the support beams near the beam enables both the ground movements and the differential dilations of the supports to be taken into account (diagram 13 and 13 bis),

c. Enables the absolute level rise between the 96 elements and the transversal and longitudinal tilt of the support beams to be recorded,

d. The recordings are permanent and enable us to watch the machine "breathe" and consequently forecast defects due to the amplitude of to great a movement.

What are the improvements to be made to the prototype? (diagram 14)

These are manufacturing improvements that can be seen by comparing diagrams 11 and 12. No functional improvement is planned and the tender documents have been send on 22 June 1989.

The latest results presented during the MAC on 13-14 March 89 (diagram 15 to 18).

We had planned to maintain a load of 3.2 tonnes in a horizontal plane with a precision greater that 10 microns. This goal was reached. The experiment was carried out over a period of four consecutive days with a servo-controlled precision greater than 1 **µm,** and by moving the motors every thirty minutes. Parallel to this, a recording was made of the motor pulses and led us to fix the jacks in a range of ±3.5**µm** probably corresponding to differential movements on each jack provided by the effects of the thermal variations. (General variation provided by external temperature and local variation provided by internal temperature). This hypothesis was well confirmed by the analysis of the following results about the very long term measurement. (diagram 19 and 20)

The latest results presented during this workshop on 31 July to 3 August 89 (diagram 19 to 20).

We can now present a very long term measurement registered during 46 days in a semi-industrial environment. In this experiment we have servo-controlled the jacks only when the movement was >= 20 **µm** always with an upward movement.

The main remarks to be made are:

_No variation registered as a function of the 5°C range of the experiment

_Small local variation of maximum 5um range connected with Civil Engineering Activities (The hypothesis of voltage variation during CW is suspected) but in any case there is no effect on the registered movement. (The effect should be controlled by an appropriate algorythm in the case of permanent servo-control) hands of less experienced operators.

N.B. A new possibility of R.M.S. measurement would seem possible with a new instrument called “The Lambda System”, manufactured by the Dutch company APPLIED LASER TECHNOLOGY. This instrument based on the principle of laser measurement of distances without contact would enable the measurement of the distance of a tensioned nylon wire with a precision greater than 0.03 mm for an R.M.S. of 0 to 1 metres. It would present the advantage of removing the carrier control and of accelerating measurement input, in comparison with the CERN Ecartometer (the progress of this new instrument will be followed with great interest).

2.2 New, modern solutions for a superior storage ring

The large number of components (608) and the concern for distributing the loads over a limited number of supports, in order to minimize the number of measuring points and the number of adjusting jacks, has led us to decide on using 160 main support beams, 64 of which will support the dipoles, and 96 the quadrupoles and sextupoles (diagram 11 and 11 bis).

The first support beams will be equipped with standard, non servo-controlled jacks and the last support beams will be equipped with monitoring equipment and the servo-controlled jacks.

2.2.1 Hydrostatic Leveling System

This system was entirely developed by the ESRF and has been presented on two occasions. On the first occasion, the aim was to demonstrate its feasibility in October 1987 after functional and critical analysis of existing hydrostatic systems[10]. The second occasion was during the MAC of 11th and 12th November 1988[11], when it was presented in poster-form giving the first results obtained.

The following is a summary of the strong points of the system:

[10] *Conception* ***d'un système*** *de* ***Contrôle altimétrique*** *automatique et permanent pour le projet ESRF, ALGE 8703, Octobre 1987*
(Systems of EDF-France, CERN, ELWAAG00l -Allemagne)

[11] *ALGE Report 8804 and 8806*

_Very good correlation between first and second curves. This means a perfect connection between HLS measurements and Stepping Motor Command.

Small offset (maximum of 5 **μm** after an abnormal displacement or refilling of the system).

_Extraordinary correlation between the external temperature and internal temperature of the building and the height differences, read by HLS with a noise lower than 1 **μm** as shown on the Zoom of the first seven days results

Even if it is difficult to quantify the part of each temperature effect (because it is a three dimensional problem connected with the exact position of each HLS on the marble in relation to the reference HLS on the wall of the building) it is very easy to qualify the two thermal effects on the ground movement registered by the 3 HLS installed on the marble.

-Reliability of the system We have already recorded a year of operation without the slightest fault either in the capacitive system or in the hydraulic system (no purge of the circuit).

2.2.2 Servo-controlled Jacks

Considering the frequency of altimetric realignment which is expected (every month or more often) and of the duration of such an operation carried out manually (approximately eight days), the presence of jacks servo-controlled from the control room is now essential. This operation should take less than two hours by multiplexing the jack controls. Then a duration of thirty minutes would be sufficient to stabilize the totality of the hydrostatic system, and consequently contribute some final supplementary corrections.

The reliability of the prototype jacks that have been used for the past nine months without incident and with frequent displacements (they were never put out of operation for more than two days at a time), has convinced us of the use of this type of screw jack driven by stepping motor. These prototypes have been used as a reference for the preparation of the tender documents for the 288 jacks which will equip the Storage Ring.

A servo-control experiment has shown us the necessity of controlling the jacks on the upward movements, in order to completely eliminate the play which will now be less than 3 **μm** (see diagram of top and bottom controlling)

2.2.3 A modern calibration base

We have seen in the last chapters that numerous results presented in the last year have been carried out thanks to the calibration base at CERN, be it for calibrating the invar wires or modem instruments such as the DI2000, for example.

The large number of measurements to be carried out on our machines will require frequent calibration operations. These calibration operations should be rapid, reliable and well adapted to the instruments of today and tomorrow (especially as far as instruments using laser sources, and non-contactor sensors are concerned. At the present time the model base in this field is that of the *Polytechnicurn de Zurich*, built in 1984, and the study of a similar base will be carried out in 1989. Its installation is planned as soon as the PINJ building is completed. It will be of use as soon as the installation of the first transfer line is underway and will be essential from the very first measurement taken of the Booster network.

CONCLUSION

A new generation of storage rings is coming into being, the solutions proposed by the ESRF in the domain of alignment are the first steps accomplished in the direction of a machine automatically controlled

The solution adopted for the permanent adjustment of the quadrupoles in the vertical plane enable the amplitude of the corrections to be reduced by permanent maintenance of the machine within strict mechanical tolerances. The proposition to maintain the machine in a mean horizontal plane of ± 100 **µm** could evolve towards a value close to 50 **µm** or perhaps even less.

Parallel solutions may perhaps be found in the future for permanent adjustment of the beam in a horizontal plane, but the absence of an absolute referential (identical to that established by the H.L.S. in the vertical plane) limits its application to relative displacements based on monitor displays. The risk of causing the beam adjustment to diverge is great and this solution can not therefore as of yet be considered.

ISR . *Correlation between the vertical closed orbit and levelling of the magnets*

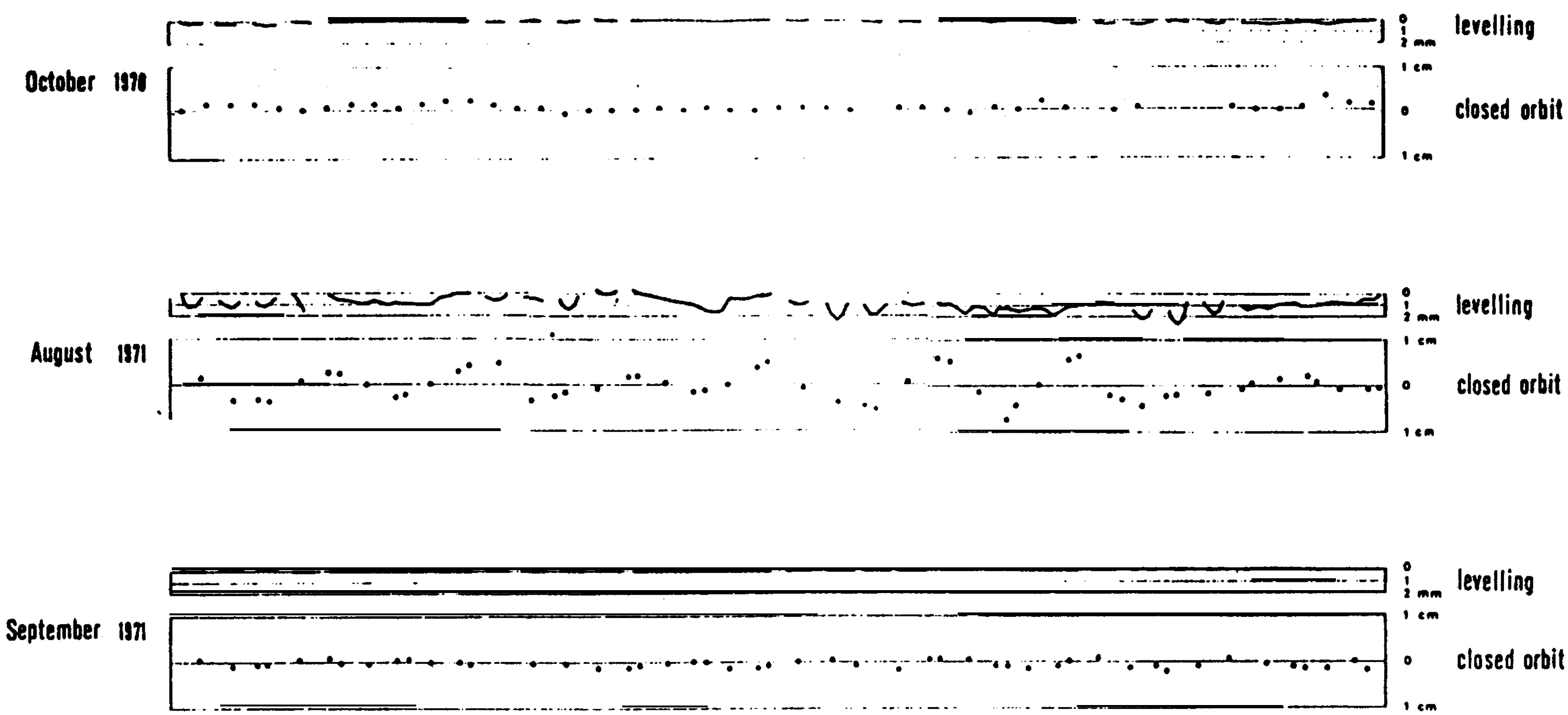
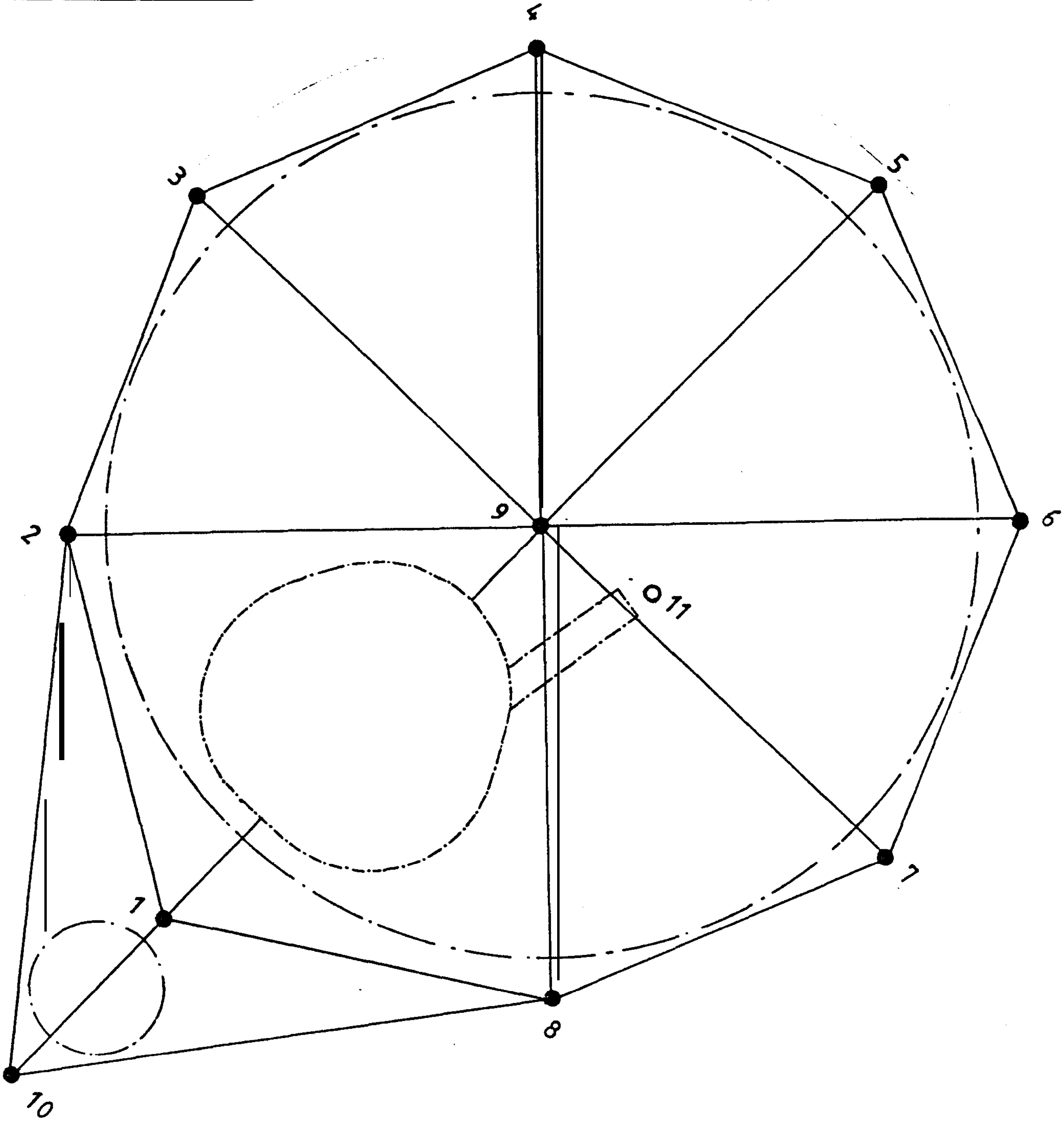


DIAGRAM 1

DIAGRAM 2 DIAGRAM OF EXTERNAL GEODETIC NETWORK

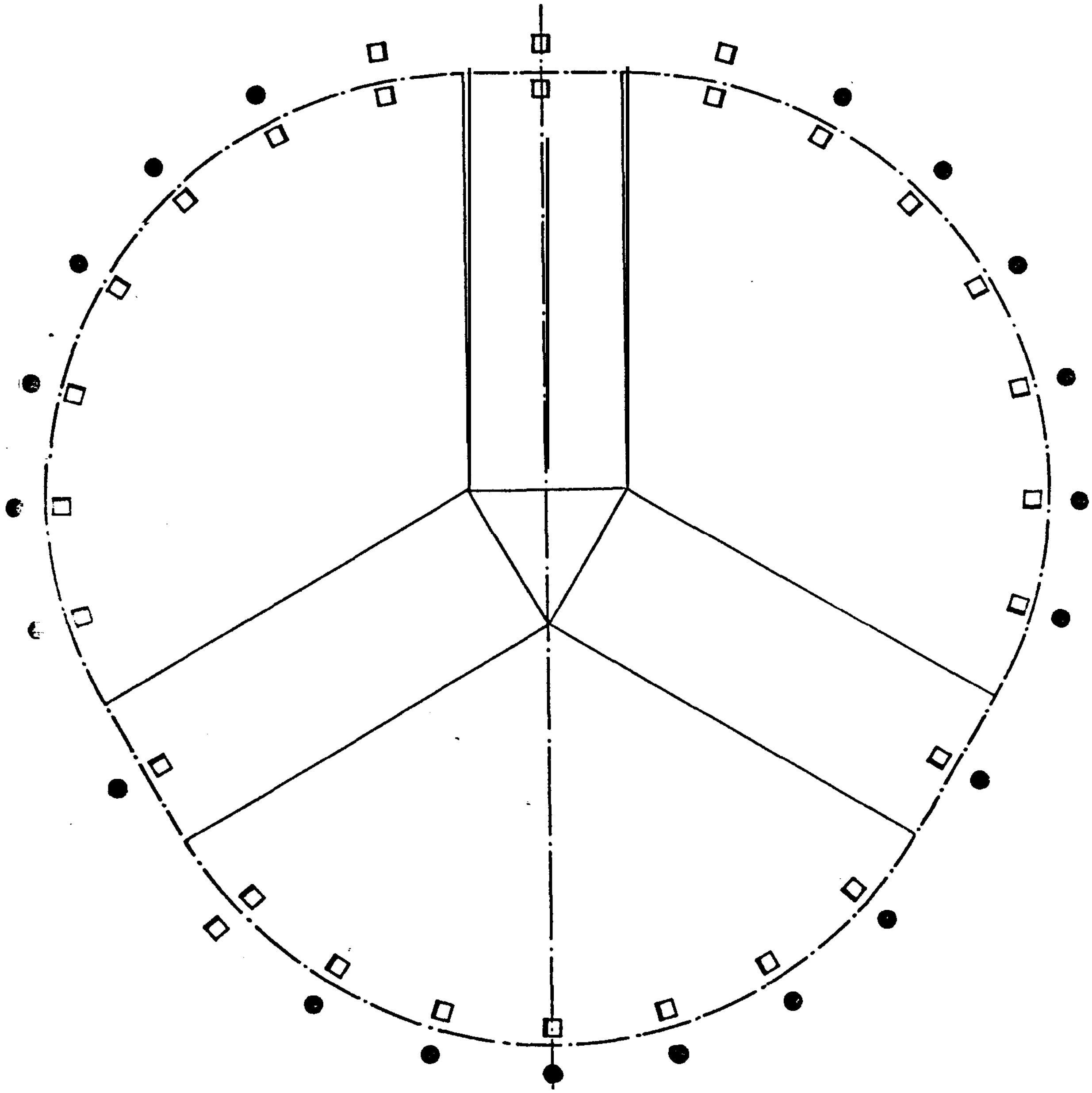


EQUIPMENT : a	11 Concrete pillars (Clear of frost)

MEASURES

DISTANCEMETER 19 Measures of distances and THEODOLITE 10 Angular Stations
or DISTANCEMETER 27 Measures of distances

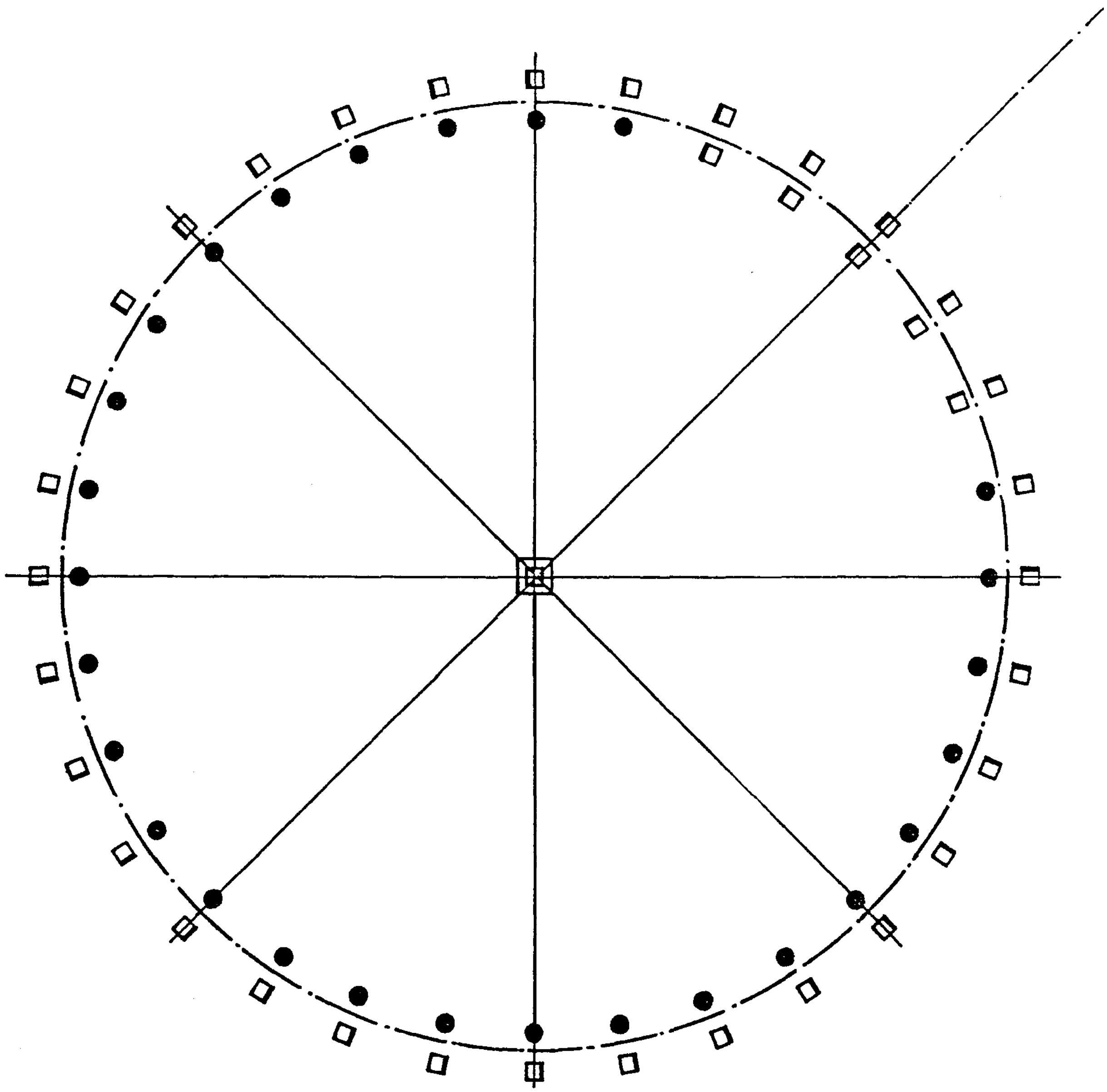
DIAGRAM - 3 DIAGRAM OF SYTU GEODETIC NETWORK



EQUIPMENT : □ 24 Concrete Pillars (Internal Ring)
□ 4 Concrete Pillars (External Ring)
● 20 Brackets on External Wall

MEASURES
DISTINVAR 147 Distance measurements
ECARTOMETER 30 Offset measurements

DIAGRAM 4 DIAGRAM OF SRTU GEODETIC NETWORK



EQUIPMENT :	□	32 Concrete Pillars (External Ring)
	□	5 Concrete Pillars (Internal Ring)
	●	27 Brackets on Internal Wall

MEASURES
DISTINVAR 128 Distance measurements
ECARTOMETER 30 Offset measurements
DISTANCEMETER 8 Radii measurements

DIAGRAM 5 — REFERENCE MARK FOR QUADRUPOLE

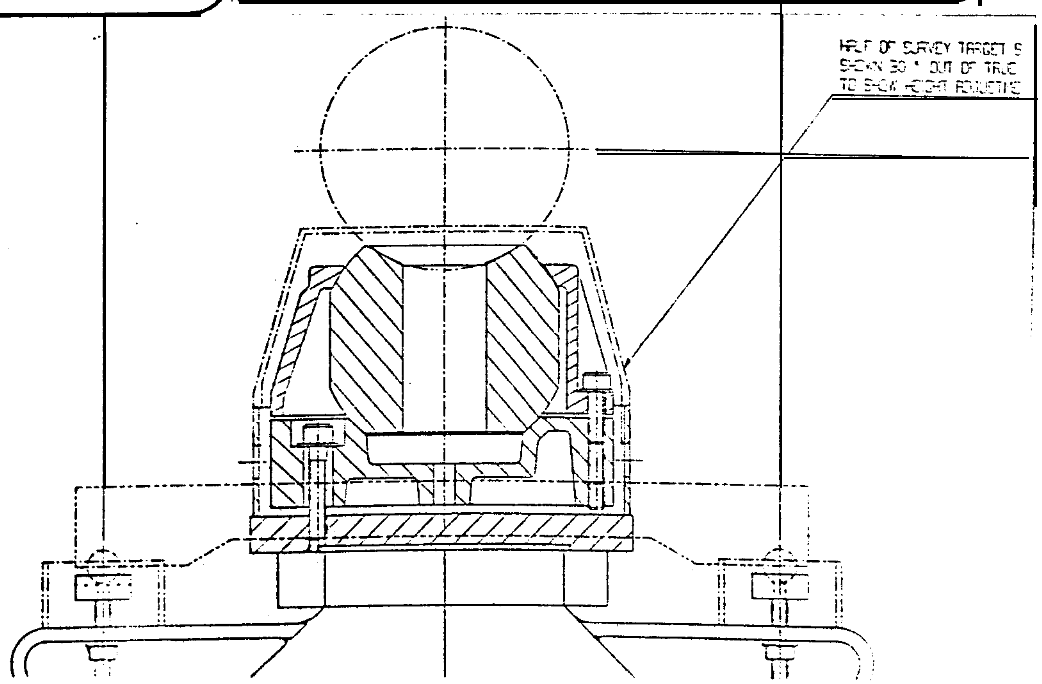


DIAGRAM 6 — REFERENCE MARK FOR DIPOLE

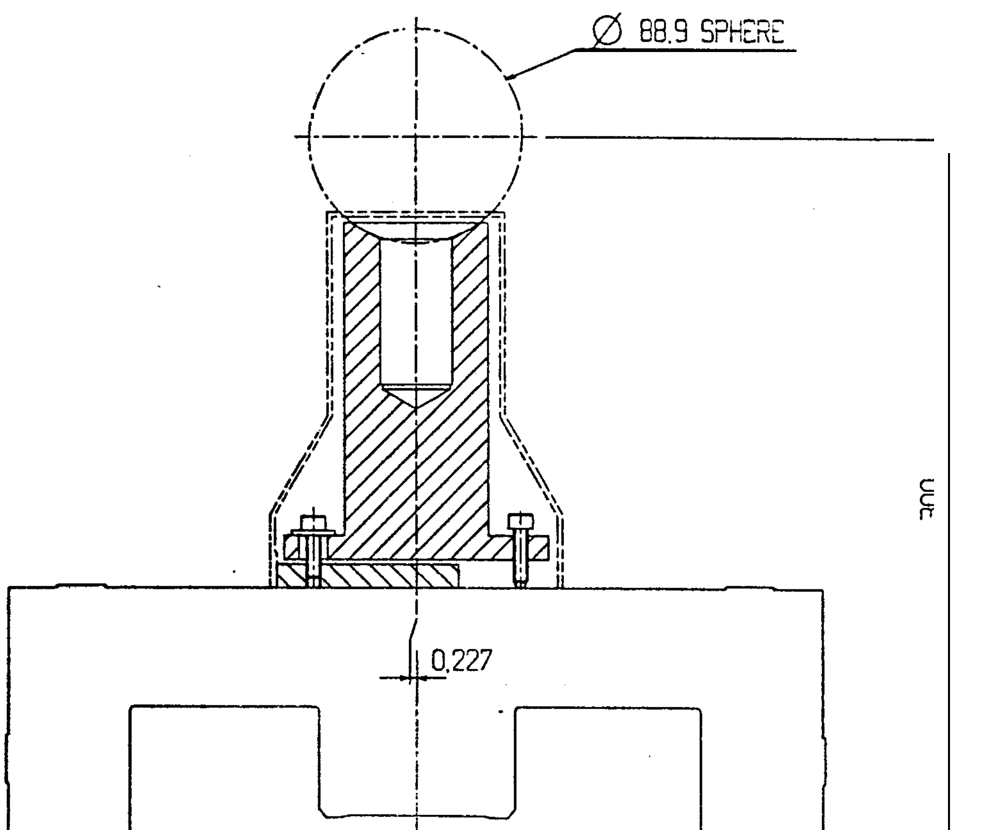


DIAGRAM 7 — MODULES OF THE SYTU

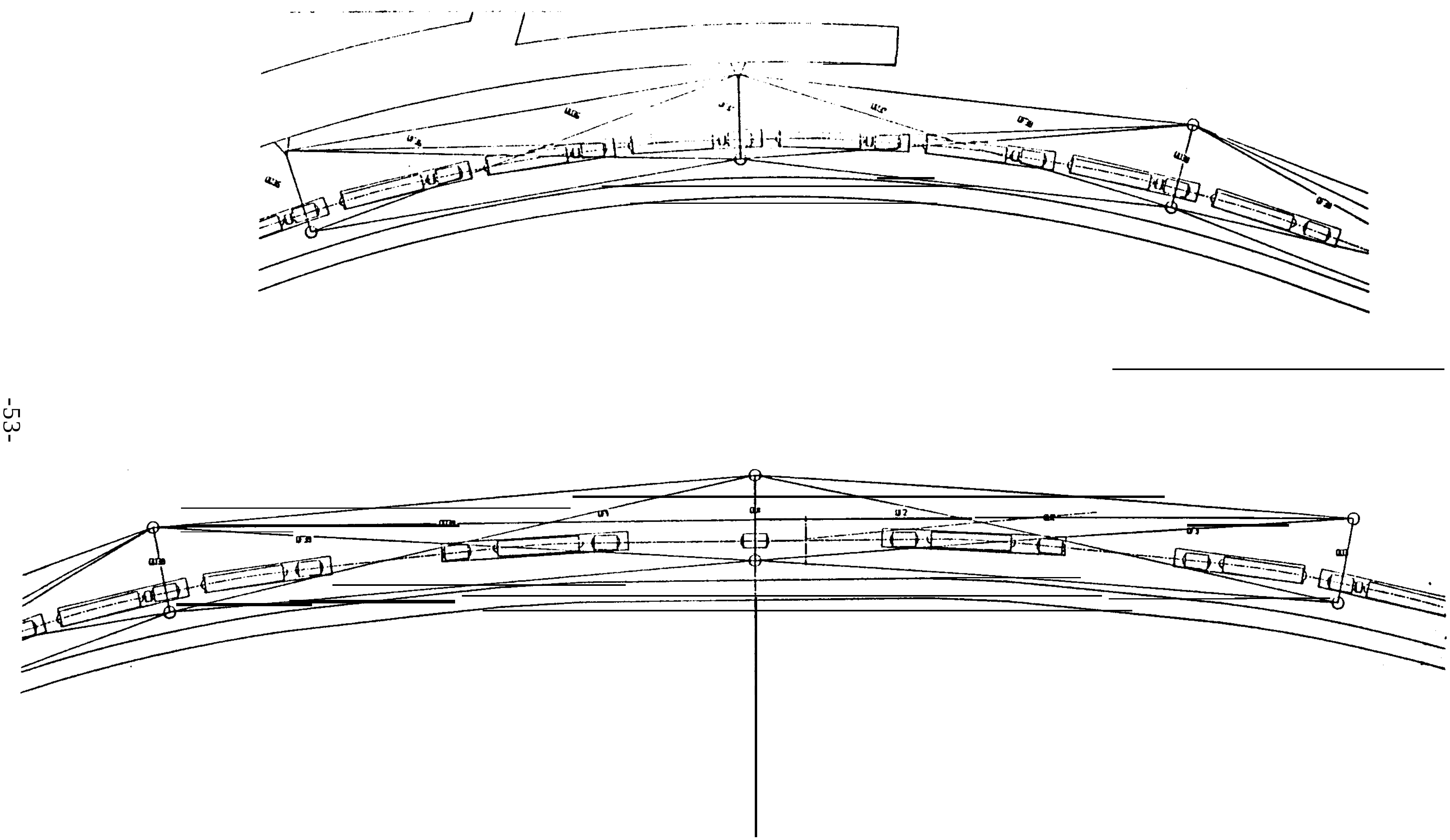


DIAGRAM 10 PRINCIPLE OF THE ECARTOMETER

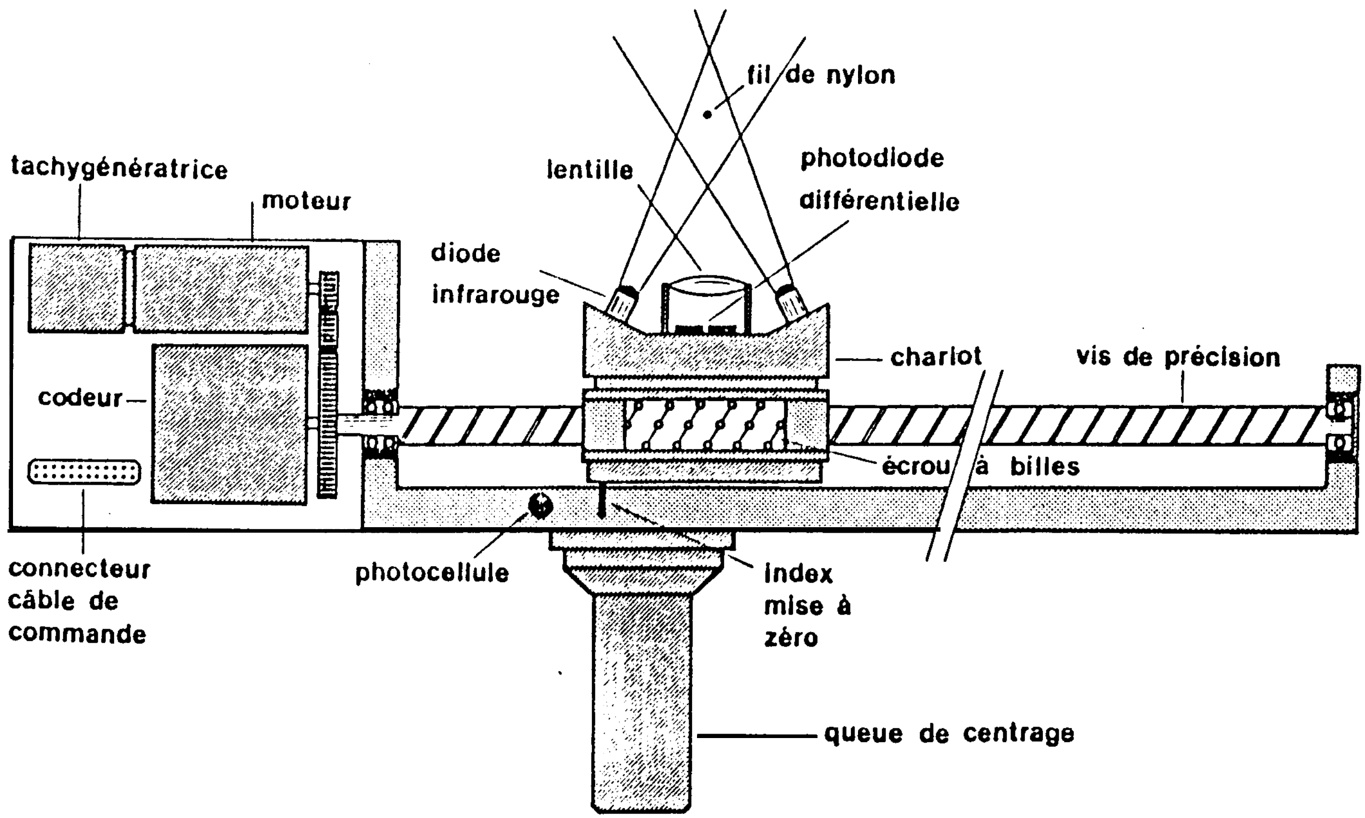


DIAGRAM 9 | PRINCIPLE O HE DIS N AR

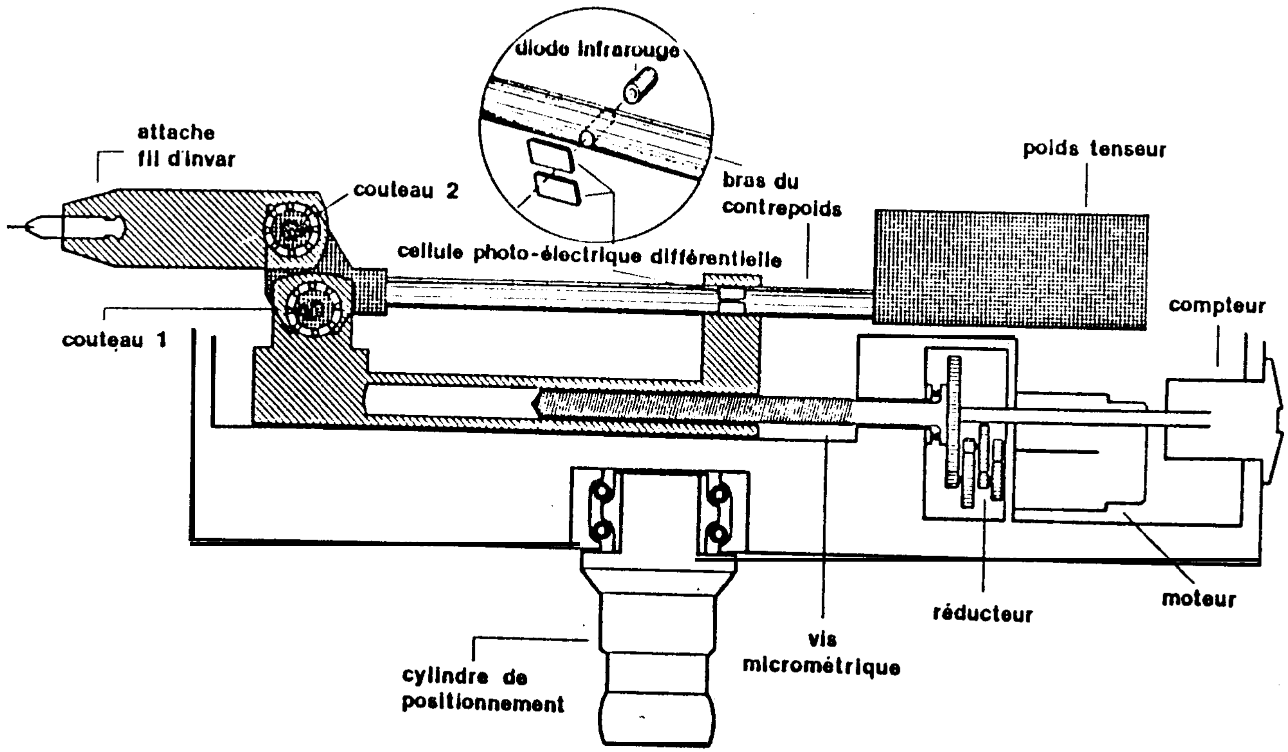


DIAGRAM 8 MODULE OF THE SRTU

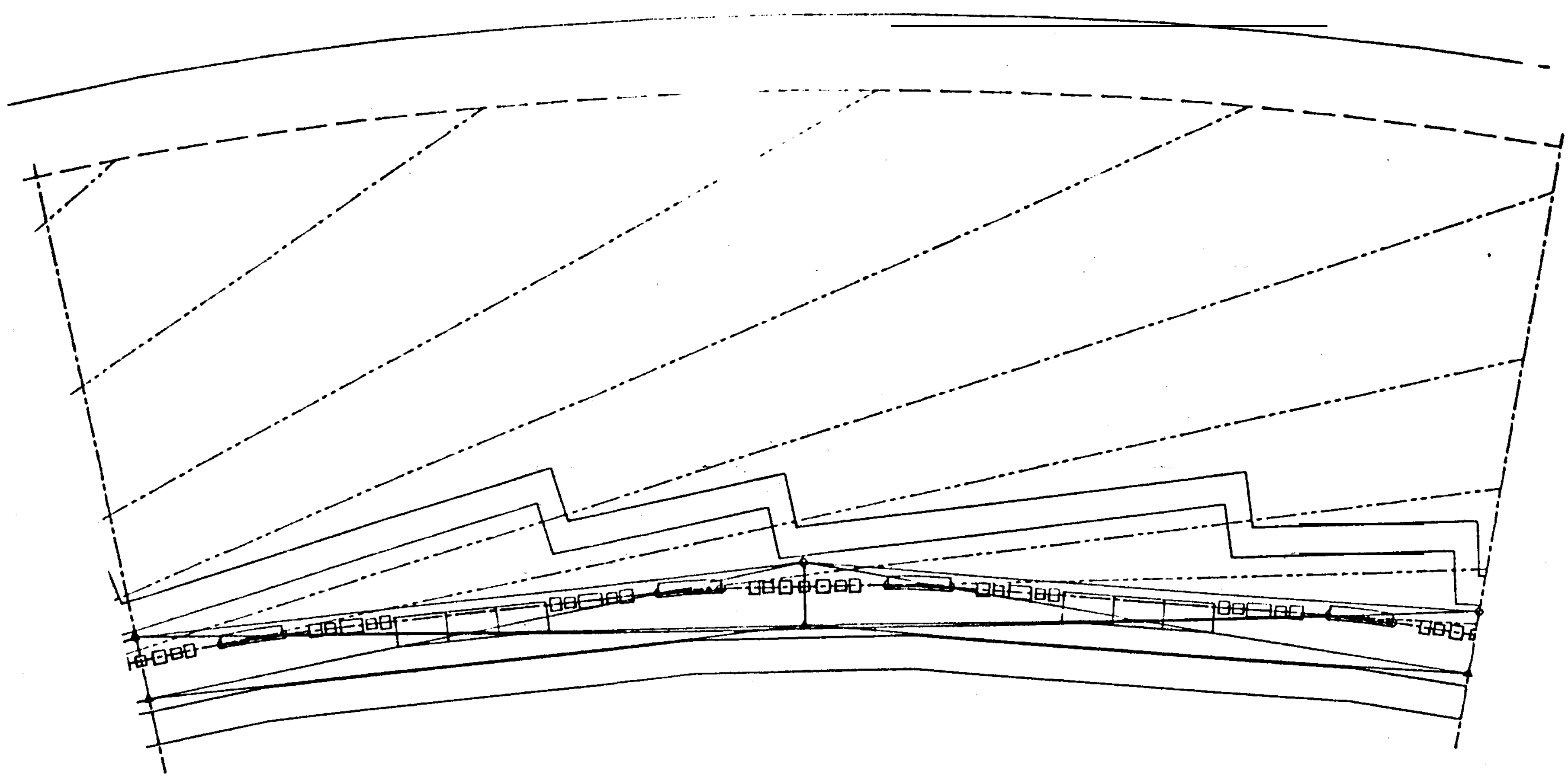
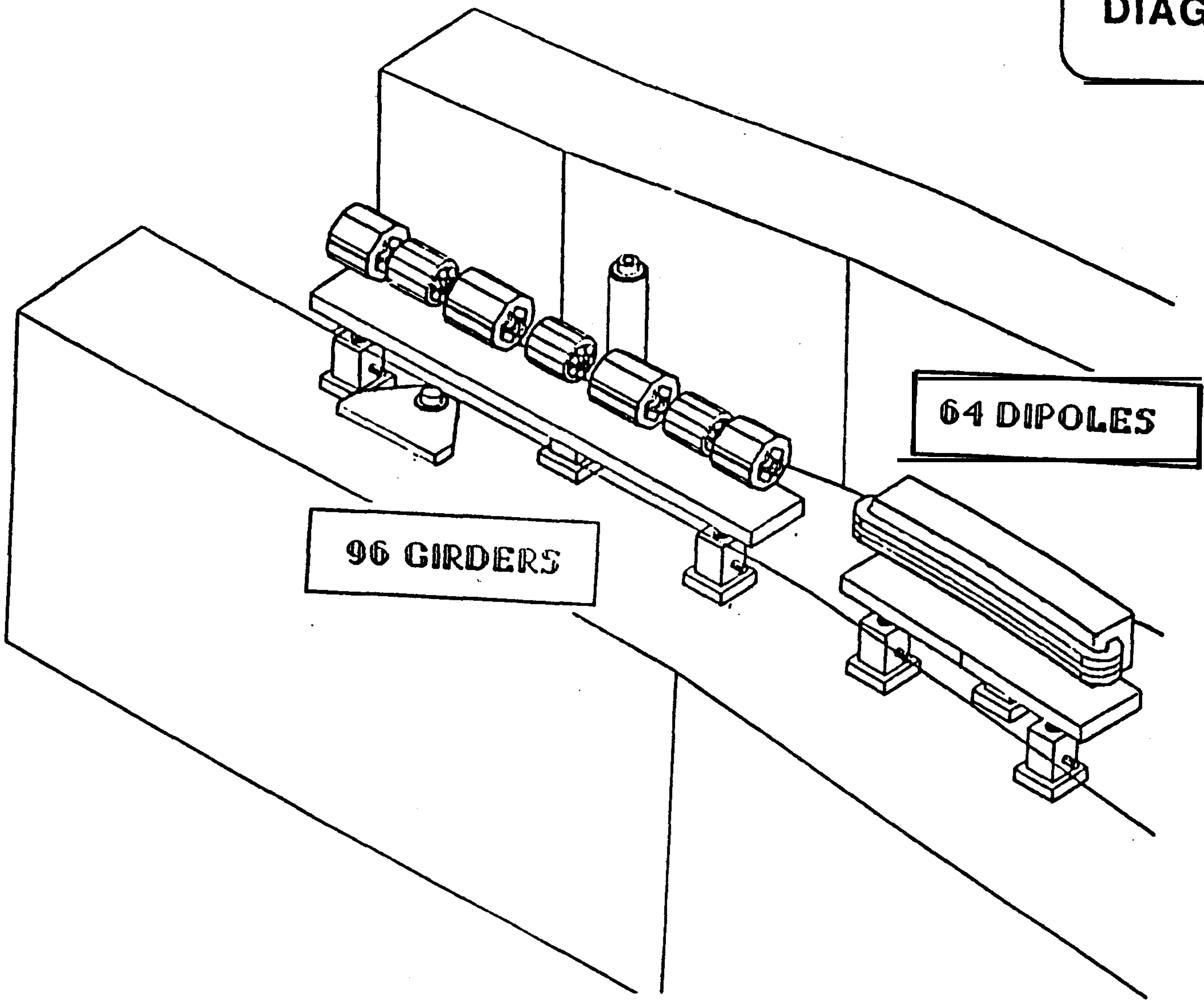


DIAGRAM 11



PROTOTYPE GIRDER LONGITUDINAL VIEW)

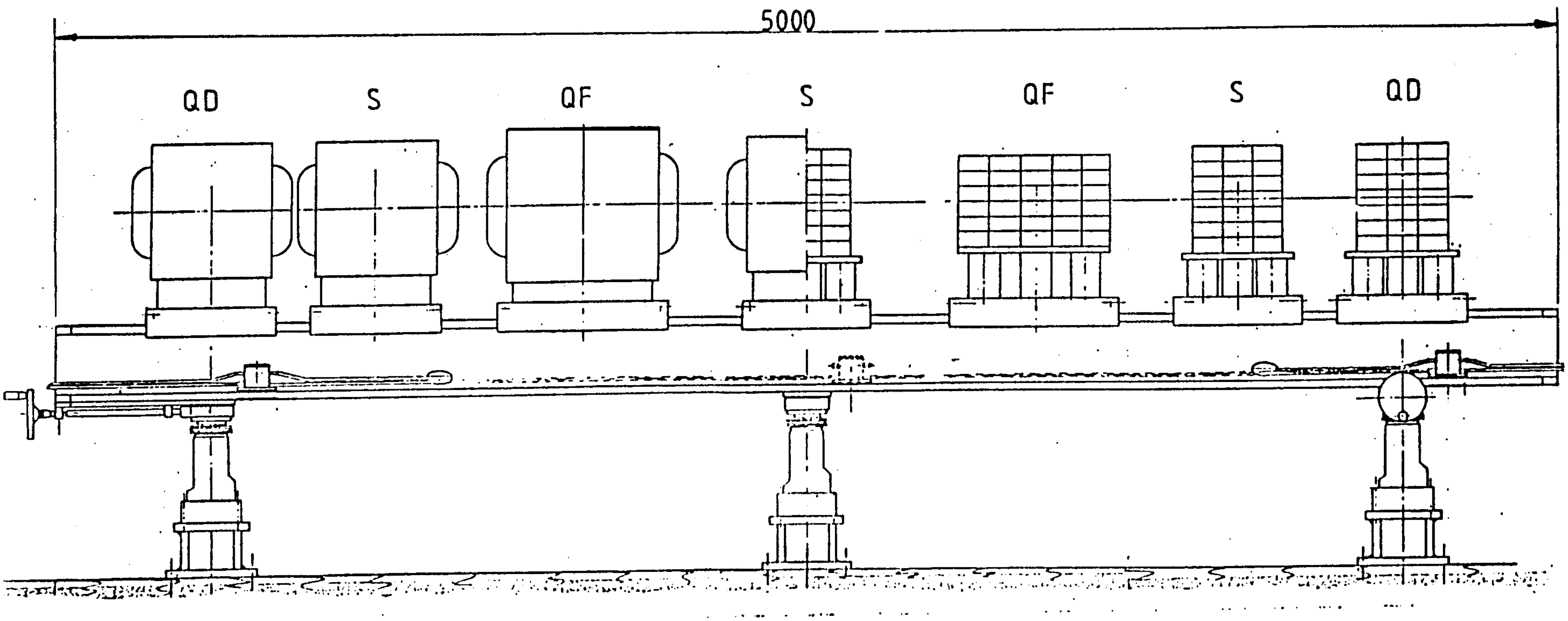
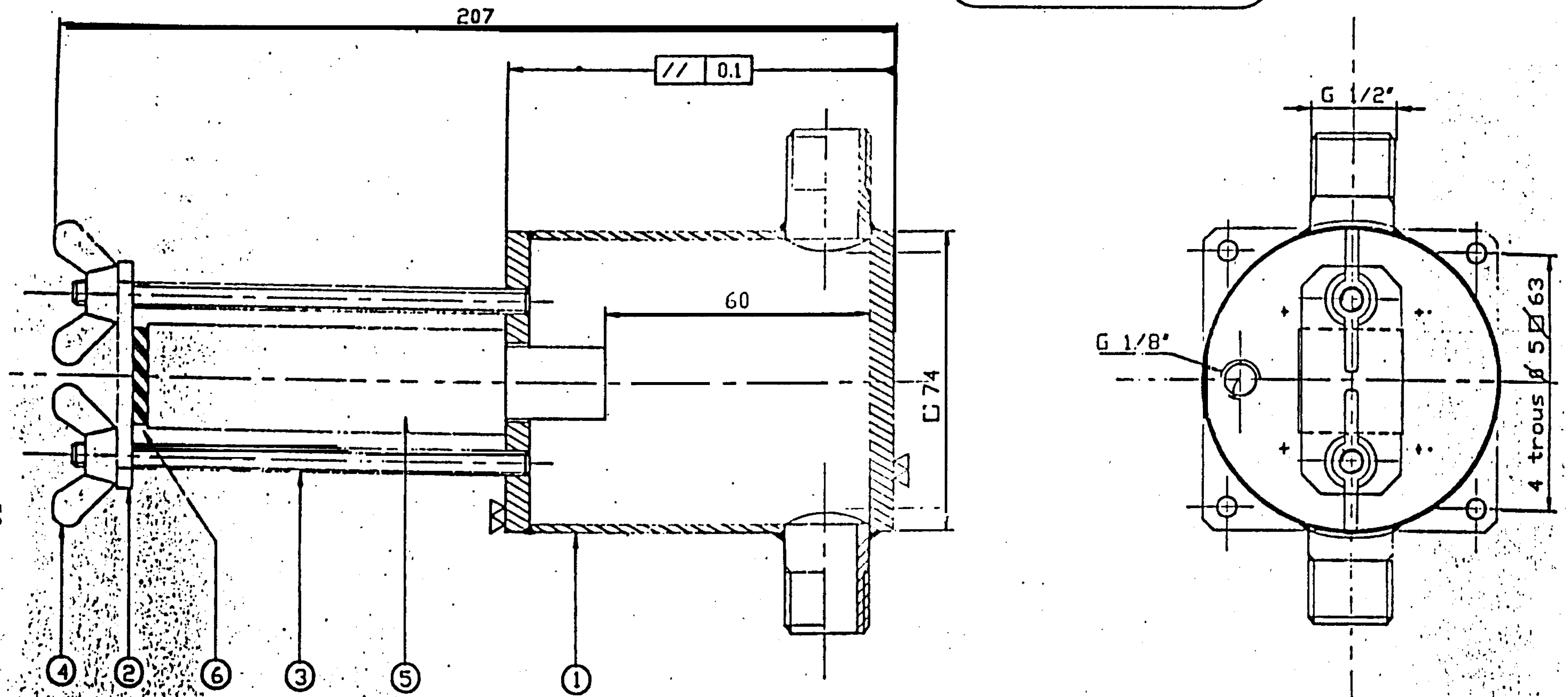


DIAGRAM 11 bis

DIAGRAM 12



⑥	1	Rondelle ep. 4 mm	Caoutchouc	
⑤	1	Capteur de proximite capacitif		
④	2	Ecrou a oreilles M6	INOX	
③	2	Tige filetee M6 - long. 115	INOX	Frein filet fort sur ①
②	1	Bride	INOX AISI 304L	
①	1	Pot de mesure	INOX AISI 304L	
REP.	NB	DESIGNATION	MATIERE	OBS

Masse : environ 1 Kg (sans raccord ni capteur)

Plans annexes : 10511 , 10512 10513

NIVELLEMENT RADIER SYNCHROTRON

Pot de mesure - Ensemble

MISE A JOUR

Verifie : JG

Dessine : CH

Date :25/9/1987

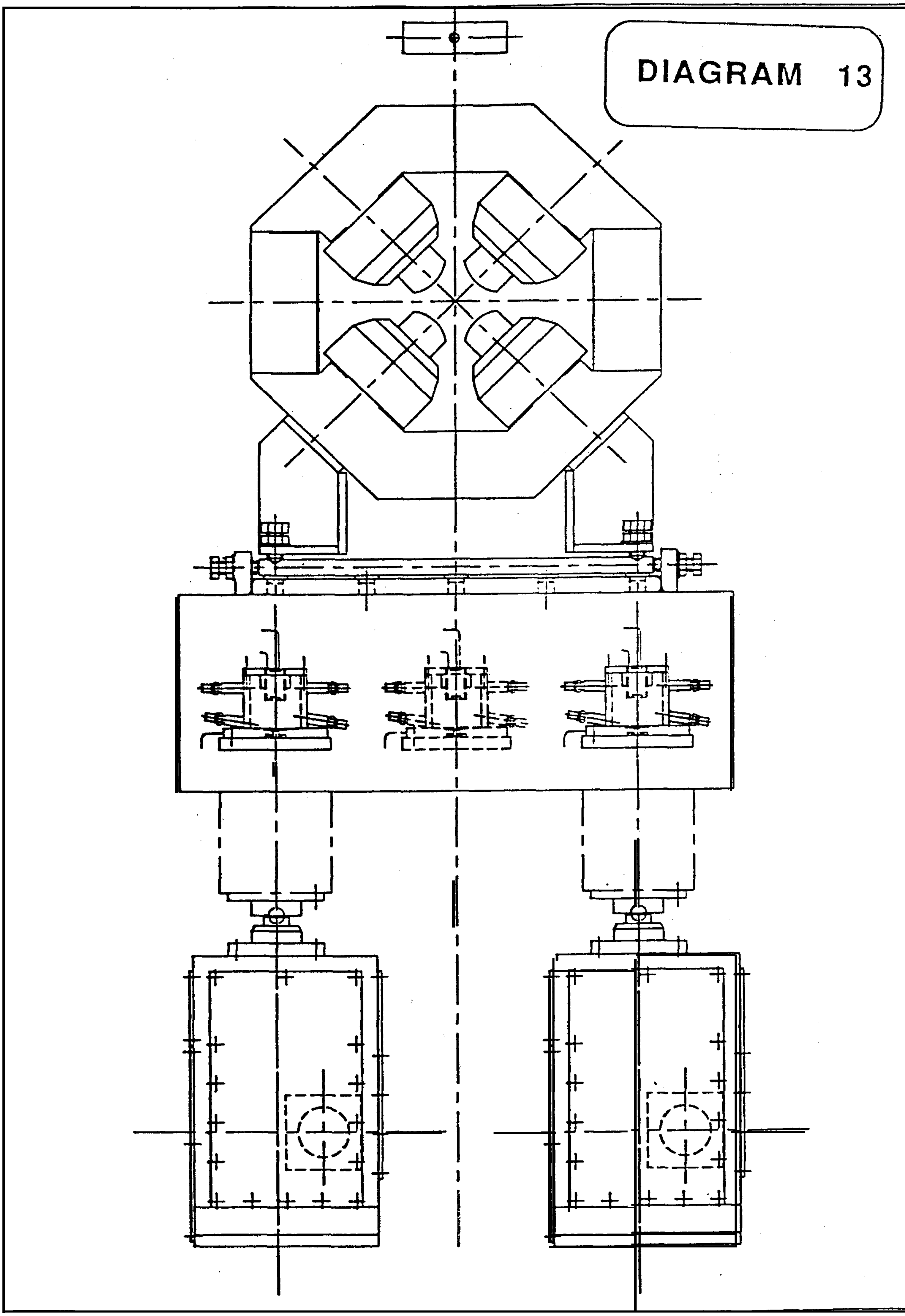
ELECTRICITE DE FRANCE

DIVISION TECHNIQUE GENERALE
37, rue Diderot
B.P. 41 Centre de tri
38040 GRENOBLE Cedex Tel 764444

ECH. 1

A3 D T G / T N N° 1 0 5 1 0

DIAGRAM 13



PROTOTYPE GIRDER (TRANSVERSAL VIEW)

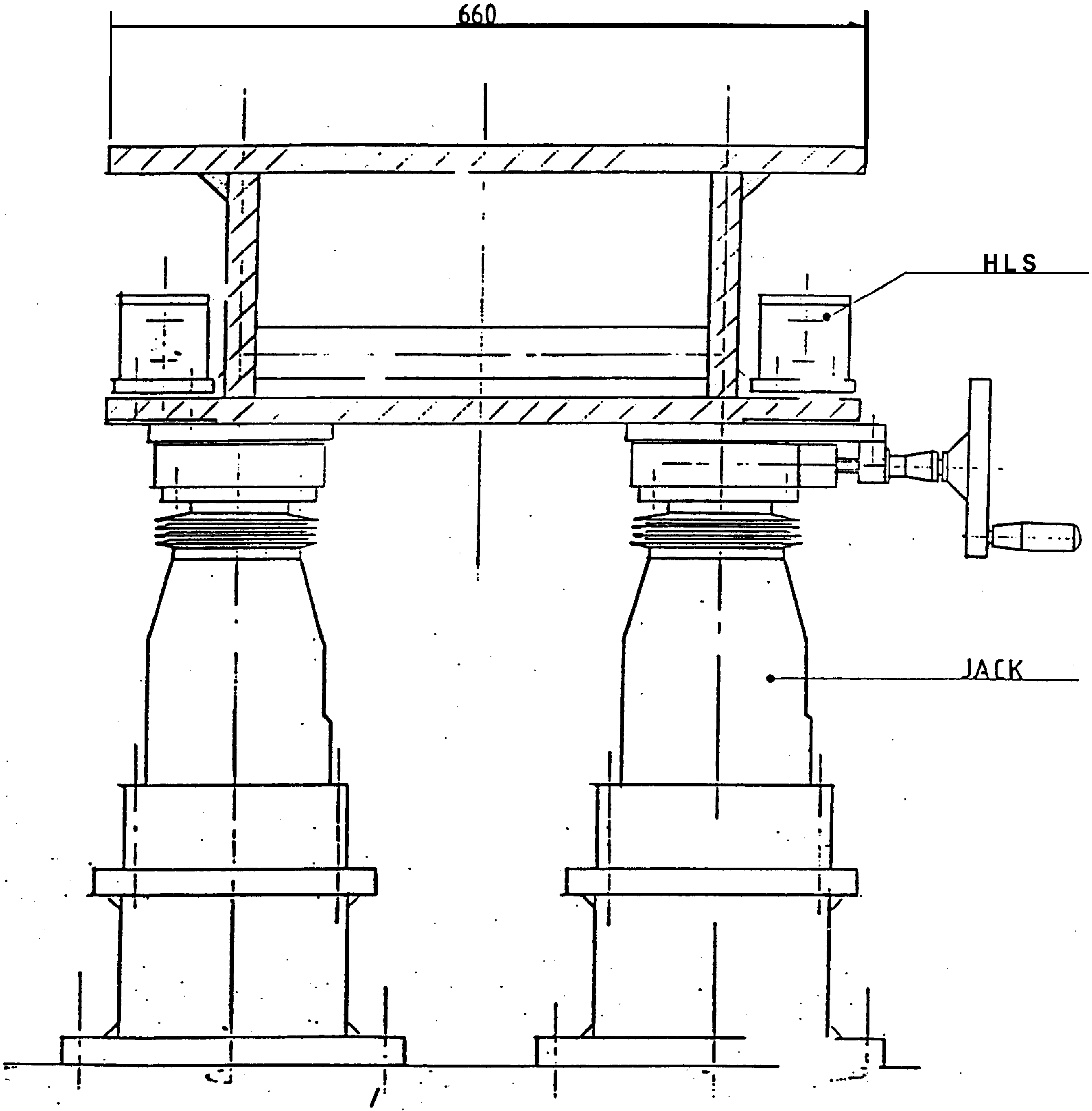
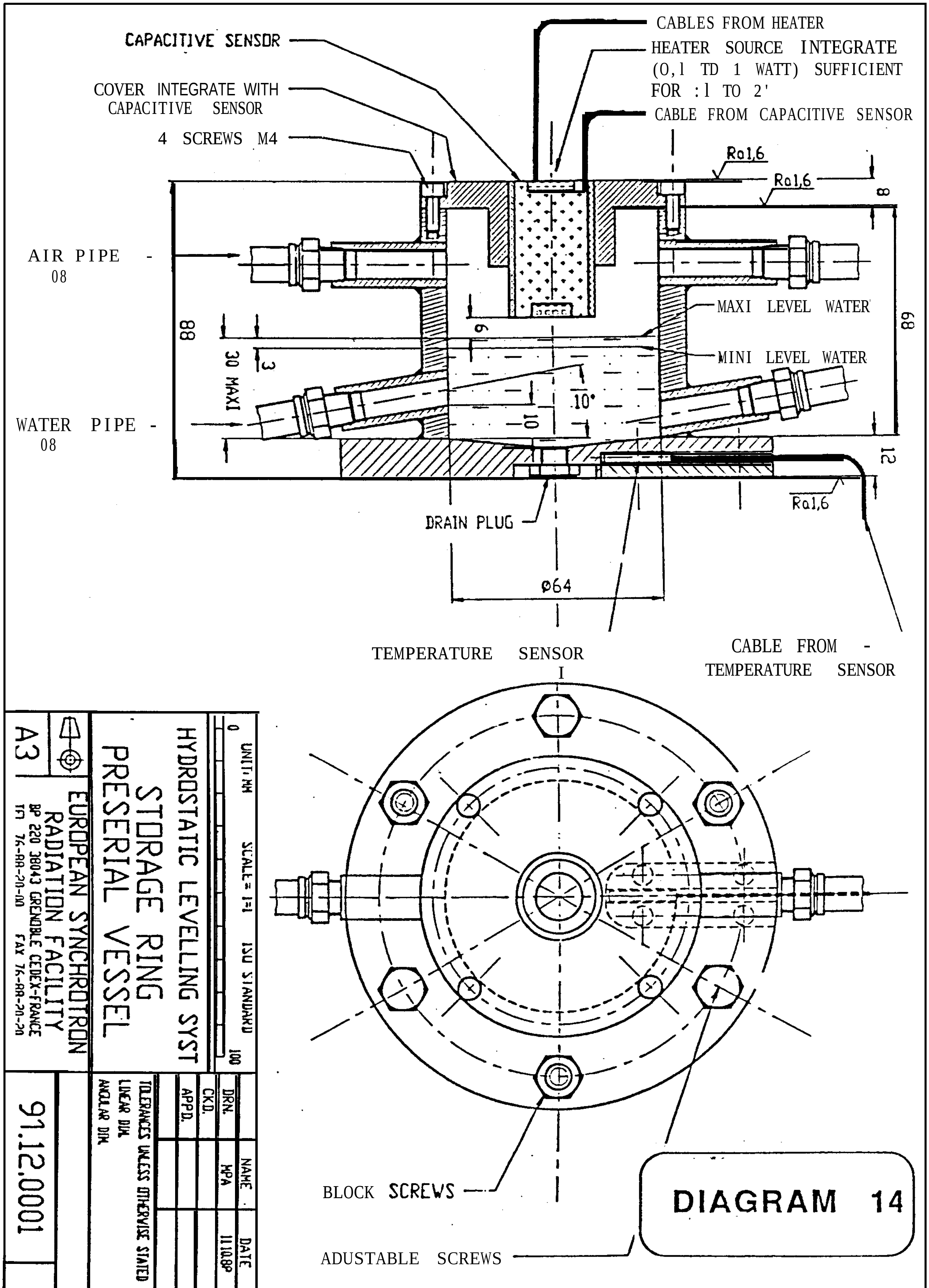


DIAGRAM 13 bis


CABLES FROM HEATER
CAPACITIVE SENSOR
HEATER SOURCE INTEGRATE (0,1 TD 1 WATT) SUFFICIENT FOR :1 TO 2'
COVER INTEGRATE WITH CAPACITIVE SENSOR
CABLE FROM CAPACITIVE SENSOR
4 SCREWS M4
Ra1,6
Ra1,6
8
AIR PIPE 08
MAXI LEVEL WATER
MINI LEVEL WATER
88
30 MAXI
3
9
10°
10
69
WATER PIPE 08
12
Ra1,6
DRAIN PLUG
ø64
TEMPERATURE SENSOR
CABLE FROM TEMPERATURE SENSOR
BLOCK SCREWS
ADUSTABLE SCREWS
DIAGRAM 14
UNIT: MM
SCALE = 1:1
ISO STANDARD
HYDROSTATIC LEVELLING SYST
STORAGE RING
PRESERIAL VESSEL
EUROPEAN SYNCHROTRON RADIATION FACILITY
BP 220 38043 GRENOBLE CEDEX-FRANCE
Tel 76-88-20-00 FAX 76-88-20-20
A3
NAME
DATE
DRN. MPA 11.10.89
CKD.
APPD.
TOLERANCES UNLESS OTHERWISE STATED
LINEAR DIM.
ANGULAR DIM.
91.12.0001

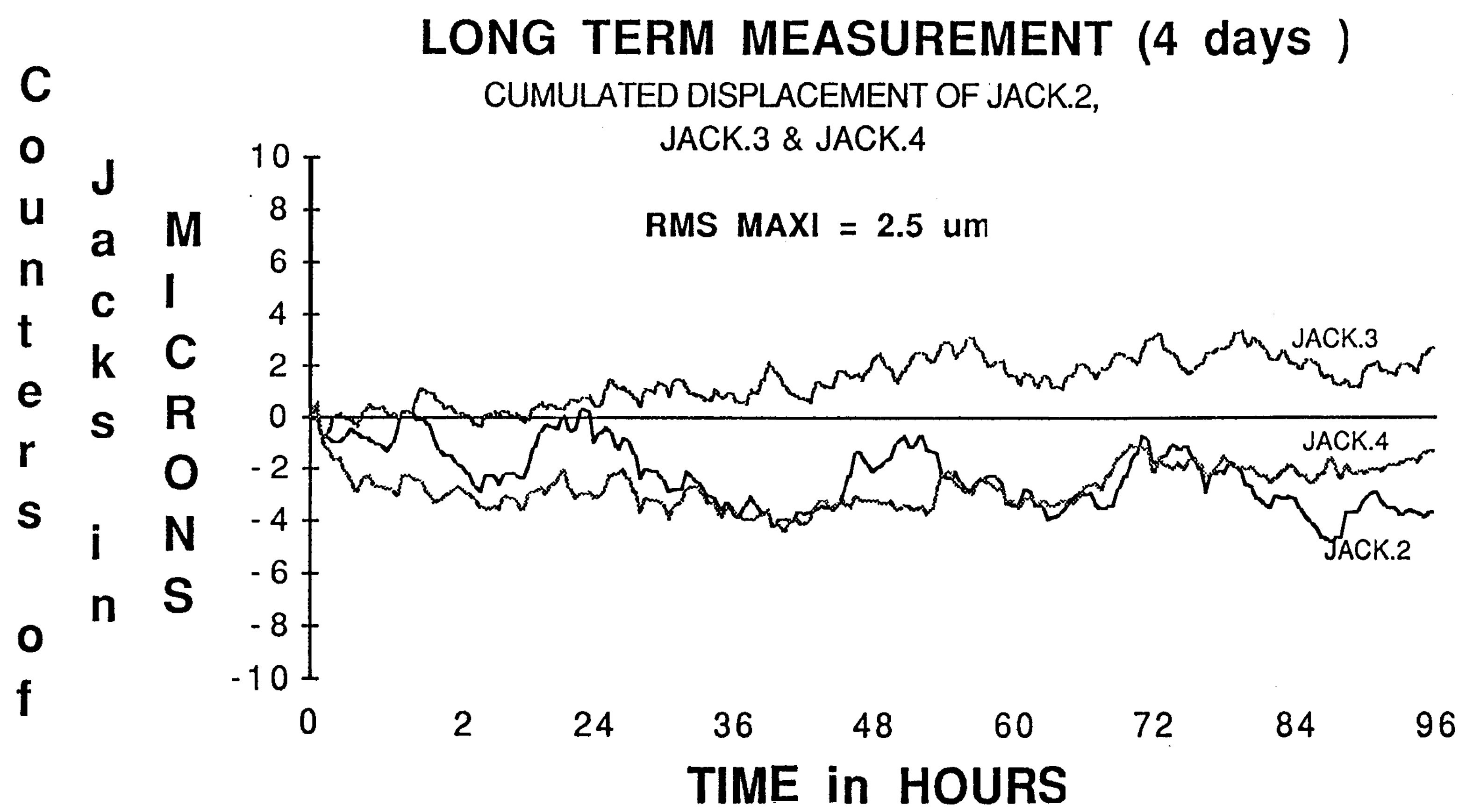

LONG TERM MEASUREMENT (4 days)
CUMULATED DISPLACEMENT OF JACK.2,
JACK.3 & JACK.4
RMS MAXI = 2.5 um
Counters of Jacks in MICRONS
10
8
6
4
2
0
-2
-4
-6
-8
-10
JACK.3
JACK.4
JACK.2
0
2
24
36
48
60
72
84
96
TIME in HOURS

DIAGRAM 15a

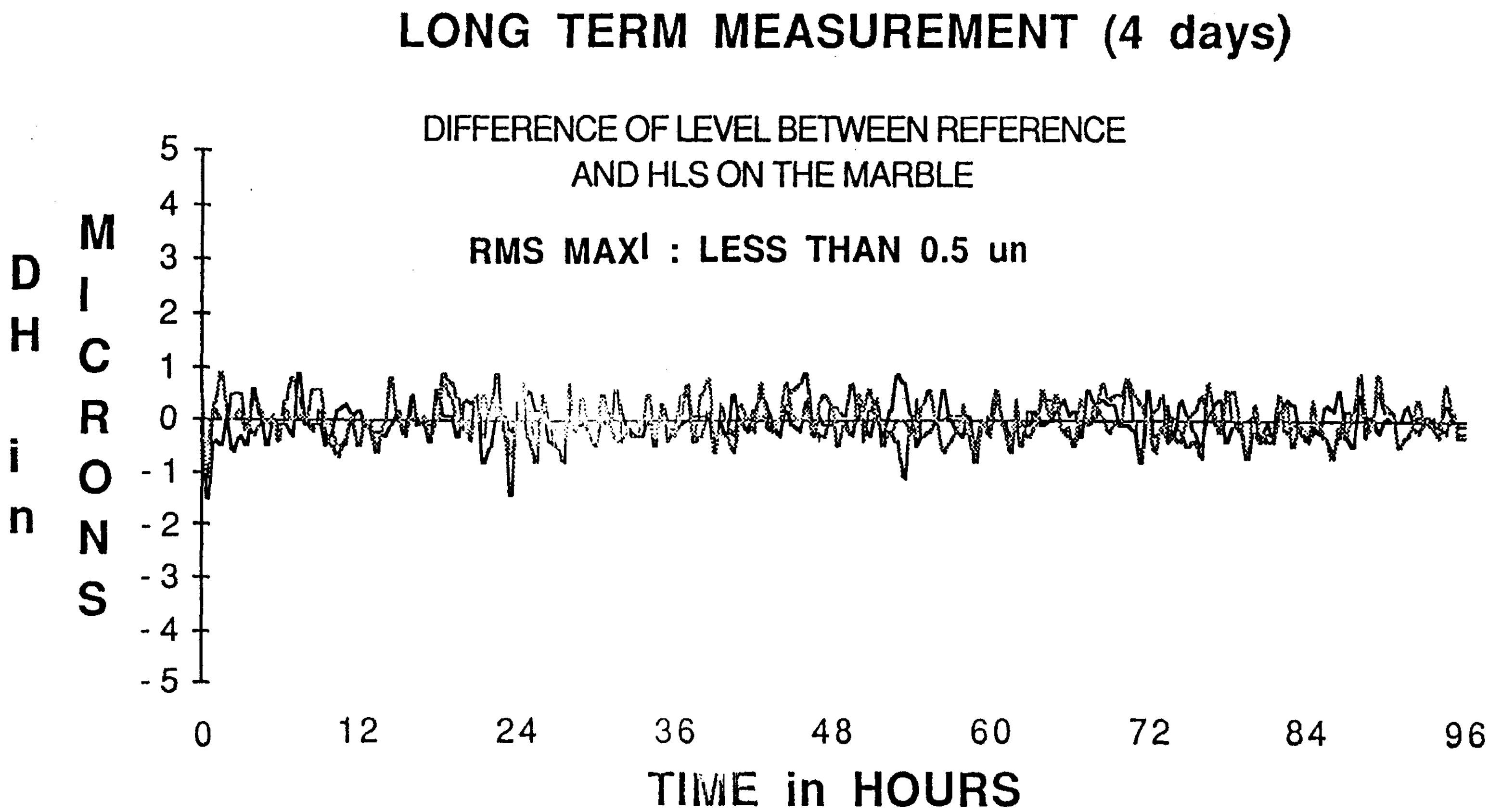
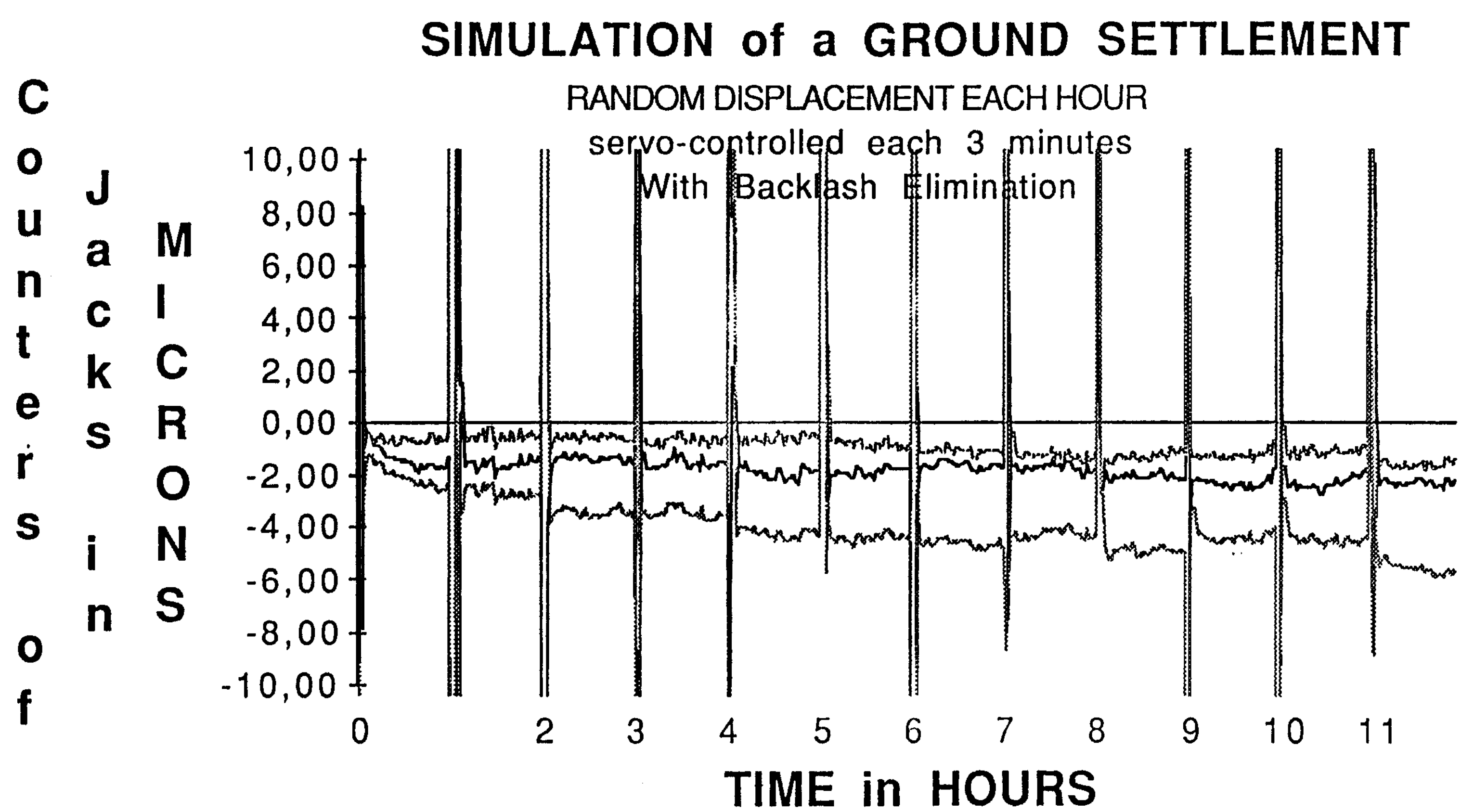

LONG TERM MEASUREMENT (4 days)
DIFFERENCE OF LEVEL BETWEEN REFERENCE
AND HLS ON THE MARBLE
RMS MAXI : LESS THAN 0.5 un
DH in MICRONS
5
4
3
2
1
0
-1
-2
-3
-4
-5
0
12
24
36
48
60
72
84
96
TIME in HOURS

DIAGRAM 15b



SIMULATION of a GROUND SETTLEMENT
RANDOM DISPLACEMENT EACH HOUR
servo-controlled each 3 minutes
With Backlash Elimination
Counters of Jacks in MICRONS
10,00
8,00
6,00
4,00
2,00
0,00
-2,00
-4,00
-6,00
-8,00
-10,00
0
2
3
4
5
6
7
8
9
10
11
TIME in HOURS

DIAGRAM 16a

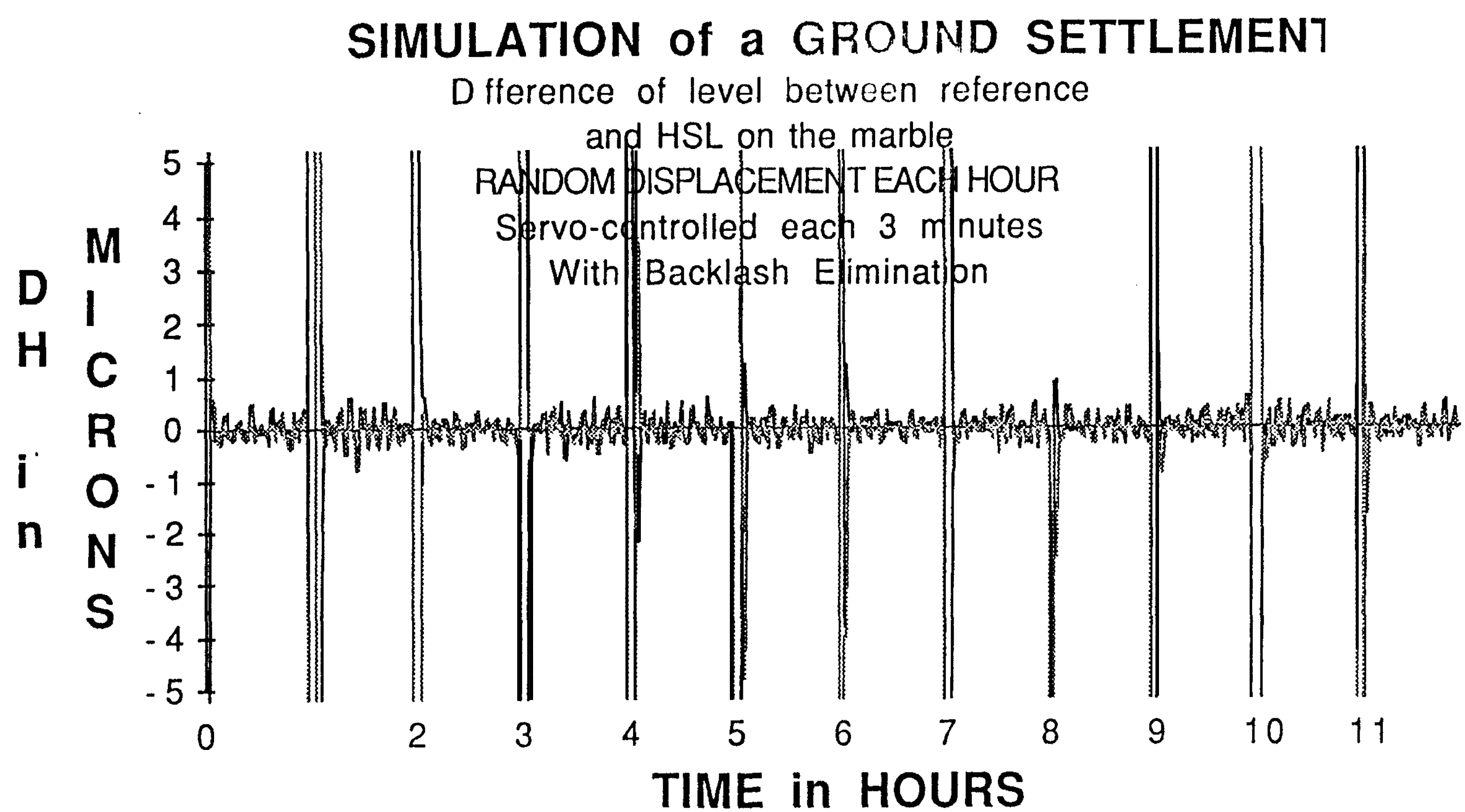

SIMULATION of a GROUND SETTLEMENT
Difference of level between reference
and HSL on the marble
RANDOM DISPLACEMENT EACH HOUR
Servo-controlled each 3 minutes
With Backlash Elimination
DH in MICRONS
5
4
3
2
1
0
-1
-2
-3
-4
-5
0
2
3
4
5
6
7
8
9
10
11
TIME in HOURS

DIAGRAM 16b

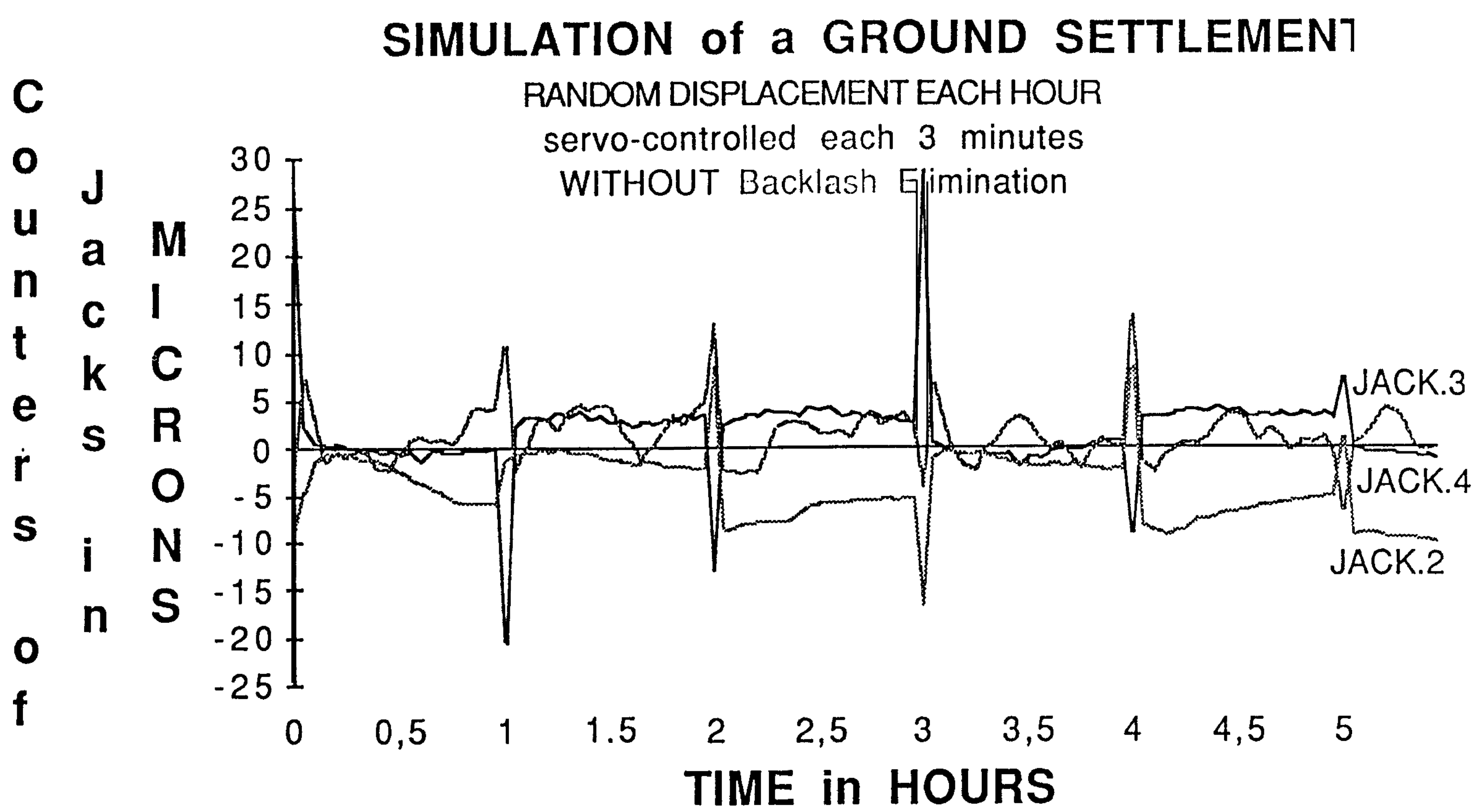

SIMULATION of a GROUND SETTLEMENT
RANDOM DISPLACEMENT EACH HOUR
servo-controlled each 3 minutes
WITHOUT Backlash Elimination
Counters of Jacks in MICRONS
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
0
0,5
1
1.5
2
2,5
3
3,5
4
4,5
5
TIME in HOURS
JACK.3
JACK.4
JACK.2

DIAGRAM 17a

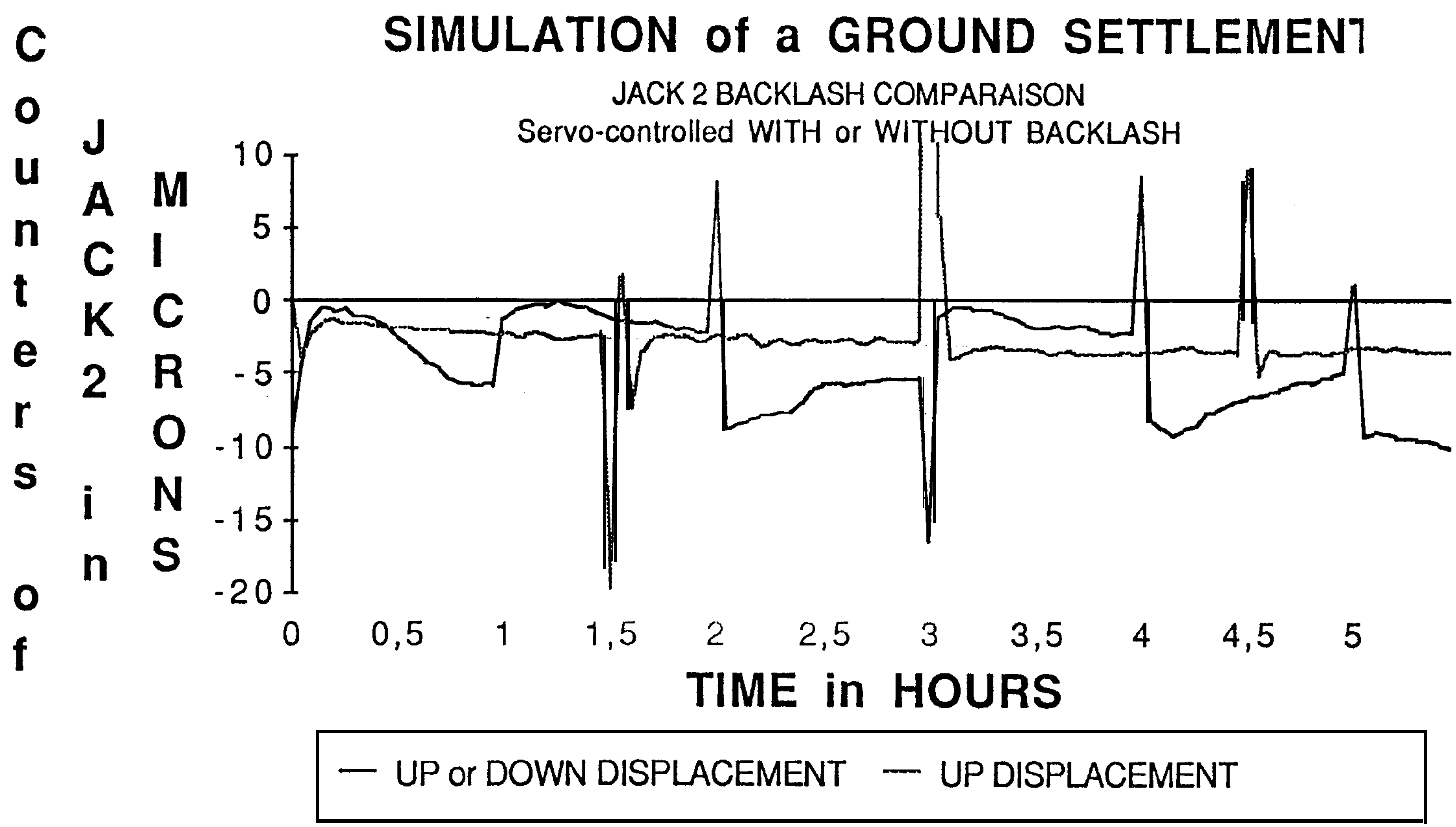

SIMULATION of a GROUND SETTLEMENT
JACK 2 BACKLASH COMPARAISON
Servo-controlled WITH or WITHOUT BACKLASH
Counters of JACK2 in MICRONS
10
5
0
-5
-10
-15
-20
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5
5
TIME in HOURS
UP or DOWN DISPLACEMENT
UP DISPLACEMENT

DIAGRAM 17b

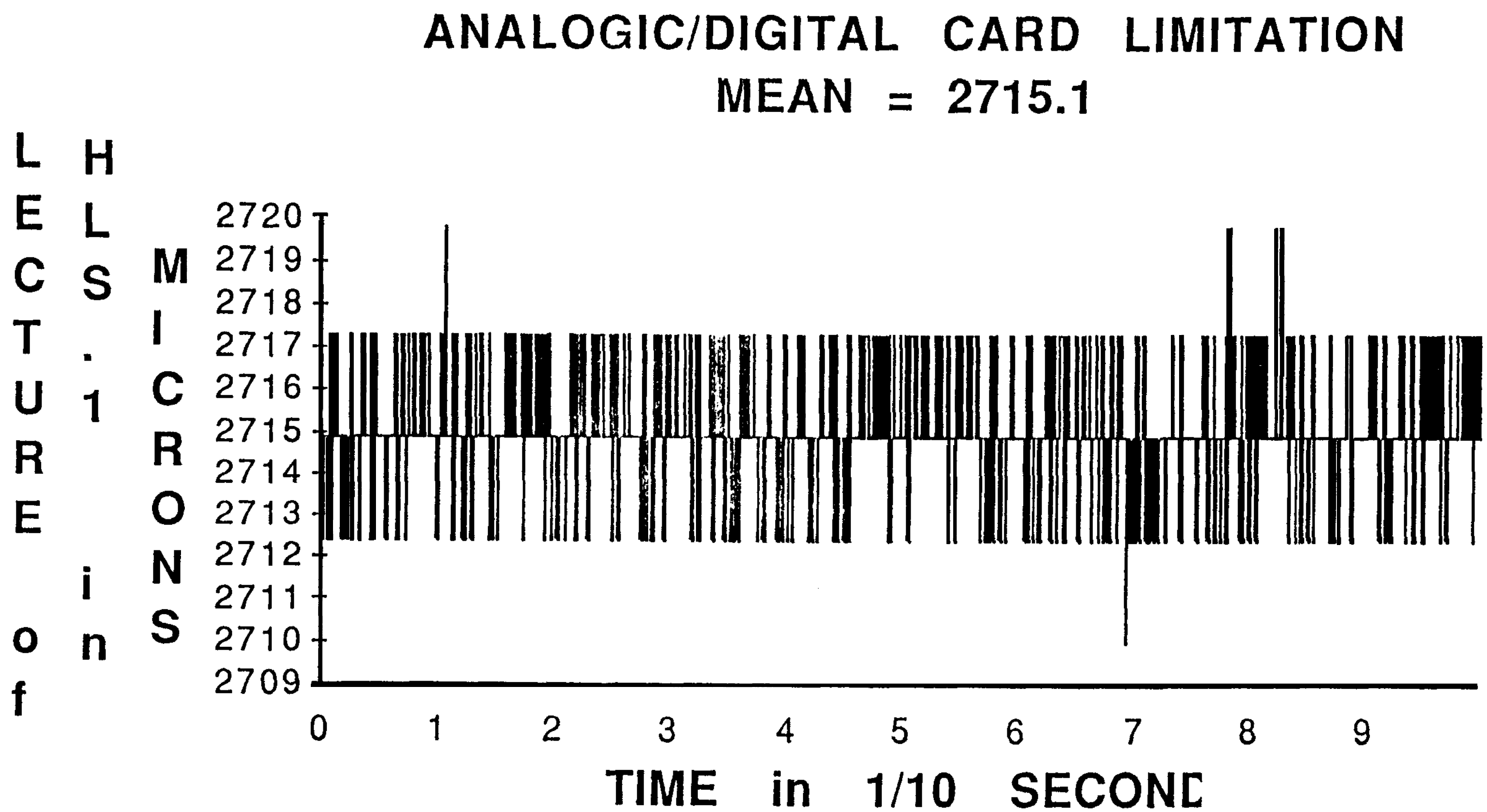

ANALOGIC/DIGITAL CARD LIMITATION
MEAN = 2715.1
LECTURE of HLS.1 in MICRONS
2720
2719
2718
2717
2716
2715
2714
2713
2712
2711
2710
2709
0 1 2 3 4 5 6 7 8 9
TIME in 1/10 SECONE

DIAGRAM 18

VERY LONG TERM MEASUREMENT (46 DAYS)

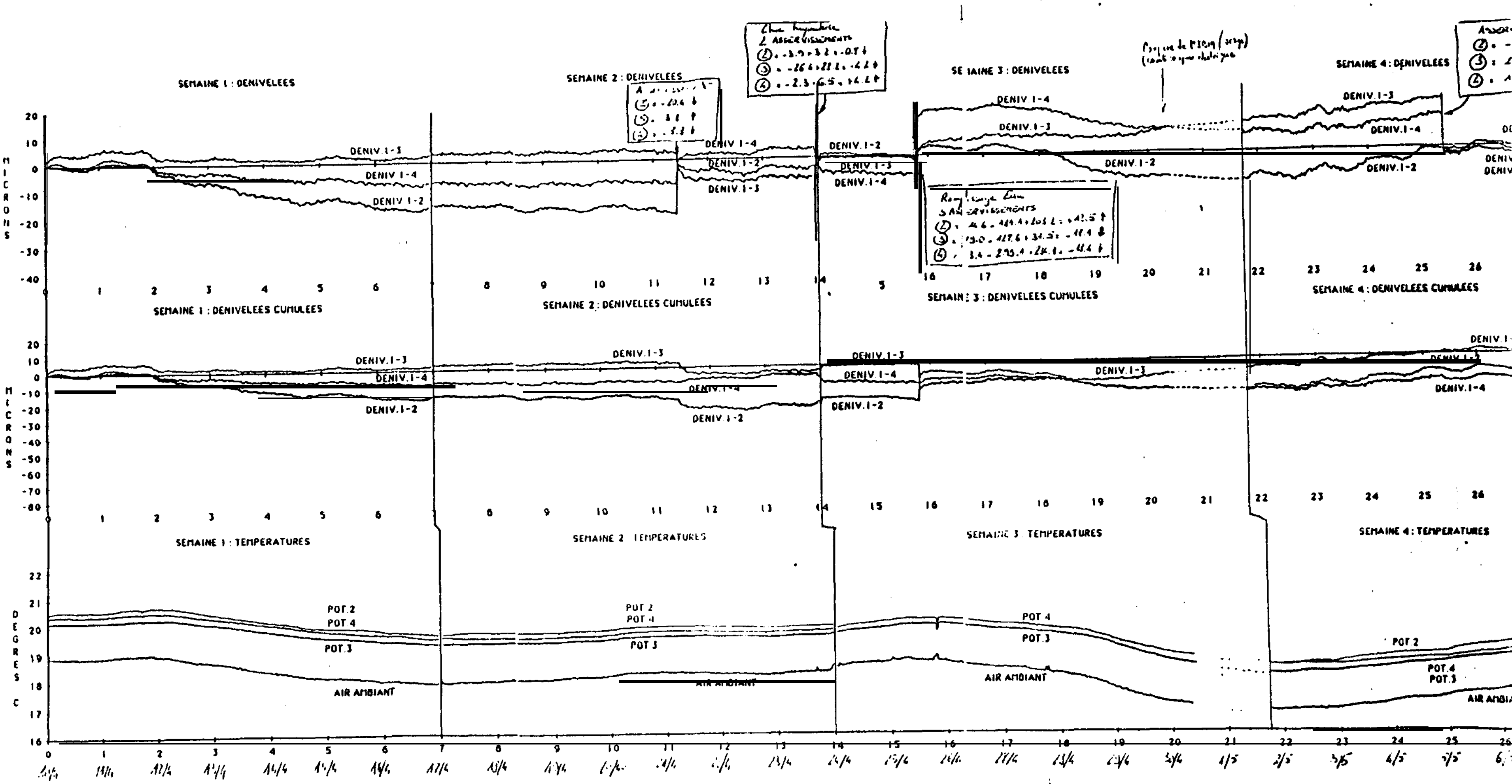


DIAGRAM 19a

VERY LONG TERM MEASUREMENT (46 DAYS)

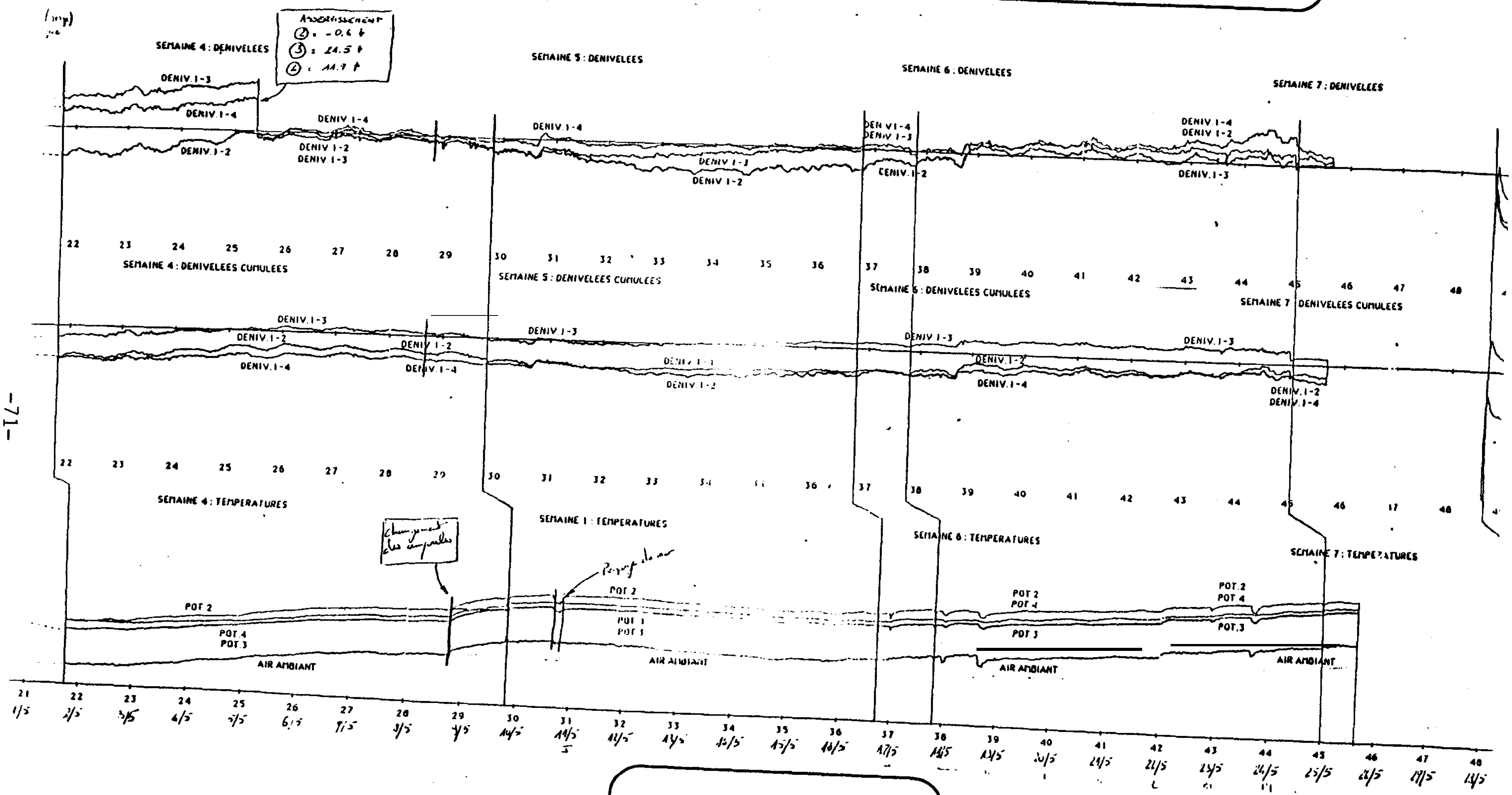
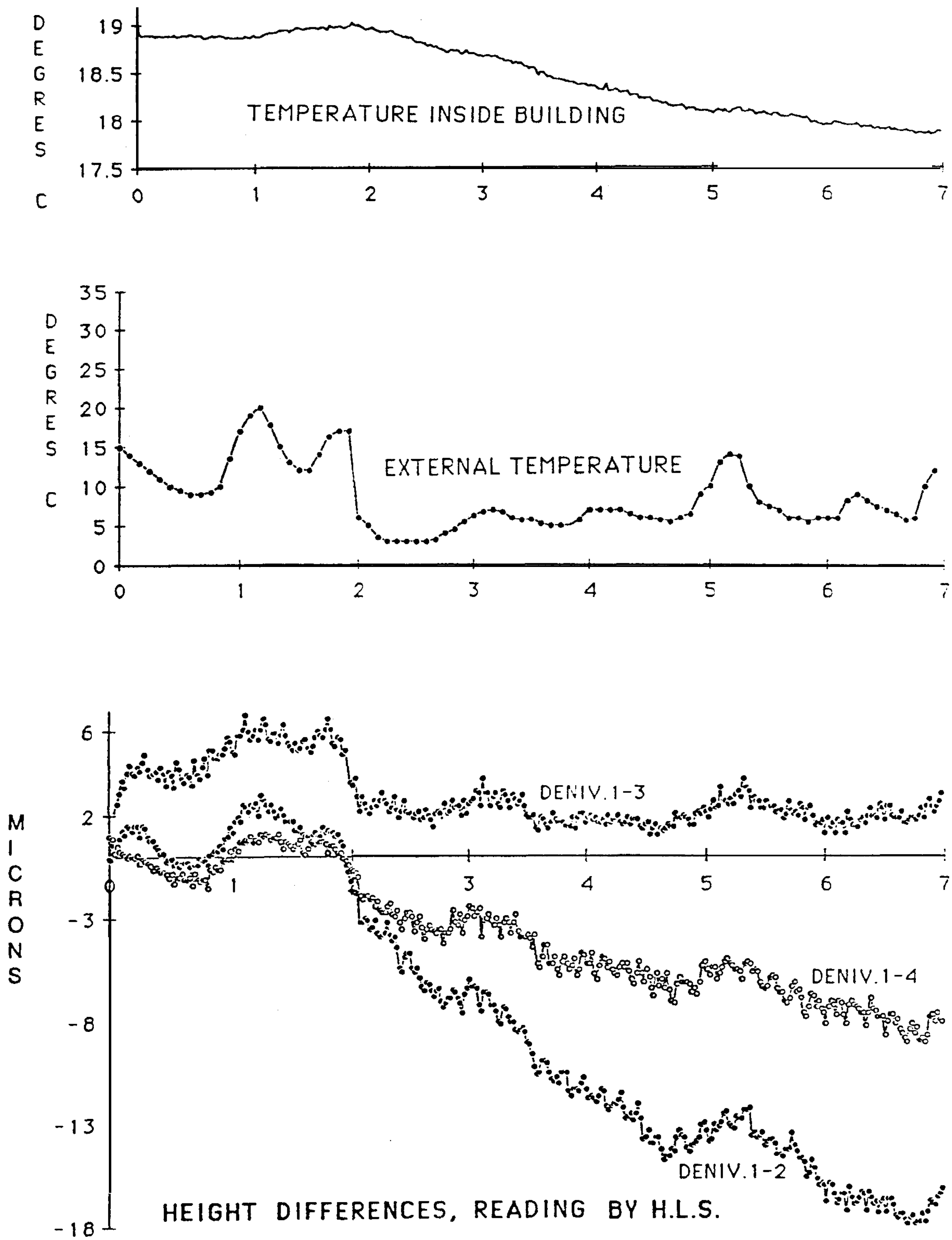


DIAGRAM 19b

ZOOM ON THE MOVEMENT OF THE SEVEN FIRST DAYS



(DIAGRAM)