RECENT DEVELOPMENTS ON CLIC[1] ALIGNMENT TESTS AND CONCEPTS

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1. CLIC SURVEY WORK FROM OCTOBER 90 TO OCTOBER 93

Tests with model N° 1 were continued and the auto-alignment program was put into its final form. The piezoelectric actuators were installed in series with the mechanical ones to increase readjustment frequency.

The model was then used to test the system and the sensors which could be used for initial alignment (optical and wire offset measurement device and clinometers).

An initial alignment method was defined and model N° 2 was set up to test it.

Considerable work was undertaken in the field of micro-seismic measurements to develop the equipment, a method of acquisition and especially a method of signal processing. Two measurement campaigns were conducted with the Protvino Institute of Physics, one in the survey experiment tunnel in which the models are installed and the other over several kilometres in LEP.

The supports for the magnet systems and an alignment method are being studied.

2. ALIGNMENT

The study concerns a machine of about 2 x 4 km. The alignment tolerances are:

- 2 μm for the Beam Position Monitor (BPM),
- 5 μm for the magnet components,
- 10 μm for the accelerating cavities.

Four accelerating cavities and a BPM are fixed and aligned on the same girder. It would be too early to mention the magnet components which will be independent of the girders without breaking their modularity. By the very design of their supports, the girders are articulated bout a notional point which is nevertheless geometrically defined in relation to the line of Vees supporting the components. All that is necessary, then, is to align these points to align the girders and hence the BPM and accelerating cavities.

Earth movement brought about by natural phenomena, human activity or the deformation of the structures where the machines are installed significantly upset the alignment. Only a dynamic alignment and real-time monitoring system can be used to guarantee such exceptional tolerances.

The installation of an accelerator begins with a *civil engineering phase* followed by a *pre-alignment phase* using conventional methods. Once attempts are made to inject beams into linear accelerators, the latters' alignment must lie within the set tolerances. To obtain such a result an automatic alignment measuring system must be active before and during the tests and the movements of the actuators maintaining the 8 km of components in the right positions must be controlled in real time. This is the *initial alignment phase.* As soon as beams are injected,

[1] CLIC : CERN Linear Collider

the position detectors distributed at regular intervals along the machine provide the actuators with data. The *auto-alignment phase* then begins. The measuring system used for initial alignment must remain active. It thus becomes the position memory of the components which is essential in a new initial alignment phase for the beam start-up after a shutdown.

The geometrical reference system consists of three regularly interconnected networks. The first, a geodetic network (measurement precision of the order of 1 mm), guarantees the absolute position of all the installations and the relative positions of points several kilometres apart. The second, an external survey network (measurement precision of the order of 0.1 mm) ensures the relative positions of points several tens of metres apart. Finally, the third, a fine survey network (measurement precision of the order of 0.001 mm) guarantees the relative positions of points a few metres apart.

All the instruments measuring these networks continuously supplies the information to a computer system which draws up their statistical analysis, calculates the position of the components and from them deduces and controls the movements to be made at the actuators.

2.1 Internal Survey Network

This network is required to determine the geometrical trajectory with the articulation points of the girders as summits and must ensure the tolerances on their relative positions. The instruments are integrated into the girders.

2.1.1 Method : Extrapolated Biaxial offset Measurement (fig. 1)

In the plane (V) passing through point 3 and perpendicular to the line (2, 3), the differences are measured on the abscissa (mx) and on the ordinate (mz) between point 3 and the point of intersection I of the line (1,2) and the plane (V).

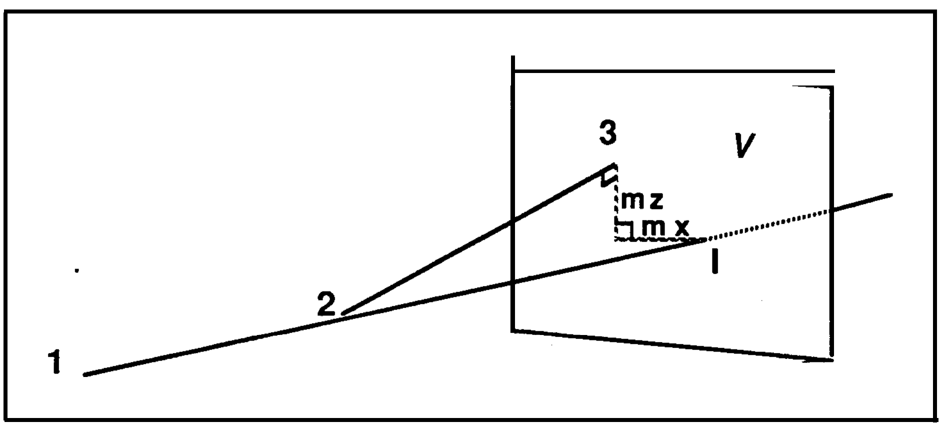

Fig 1

2.1.2. Instrument : Optical Offset Measurement Device (fig. 2)

A four-quadrant cell (termed the receiver) and a luminous object (termed the emitter) are located on the optical axis of a thin lens at twice the focal length on either side of it. The emitter is a luminous square produced by a mask fitted on a ground-glass screen lit by a infrared light source. The reference straight line is defined by the emitter and the lens. The offsets are measured on the receiver.

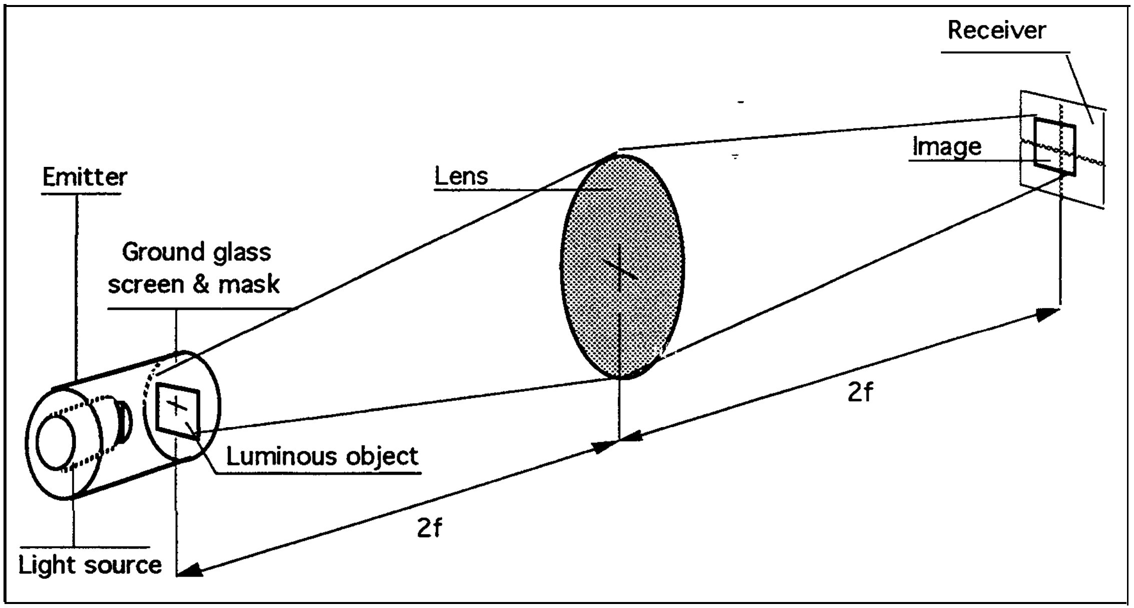
Receiver
Image
Emitter
Lens
Ground glass
screen & mask
Luminous object
2f
2f
Light source

Fig. 2

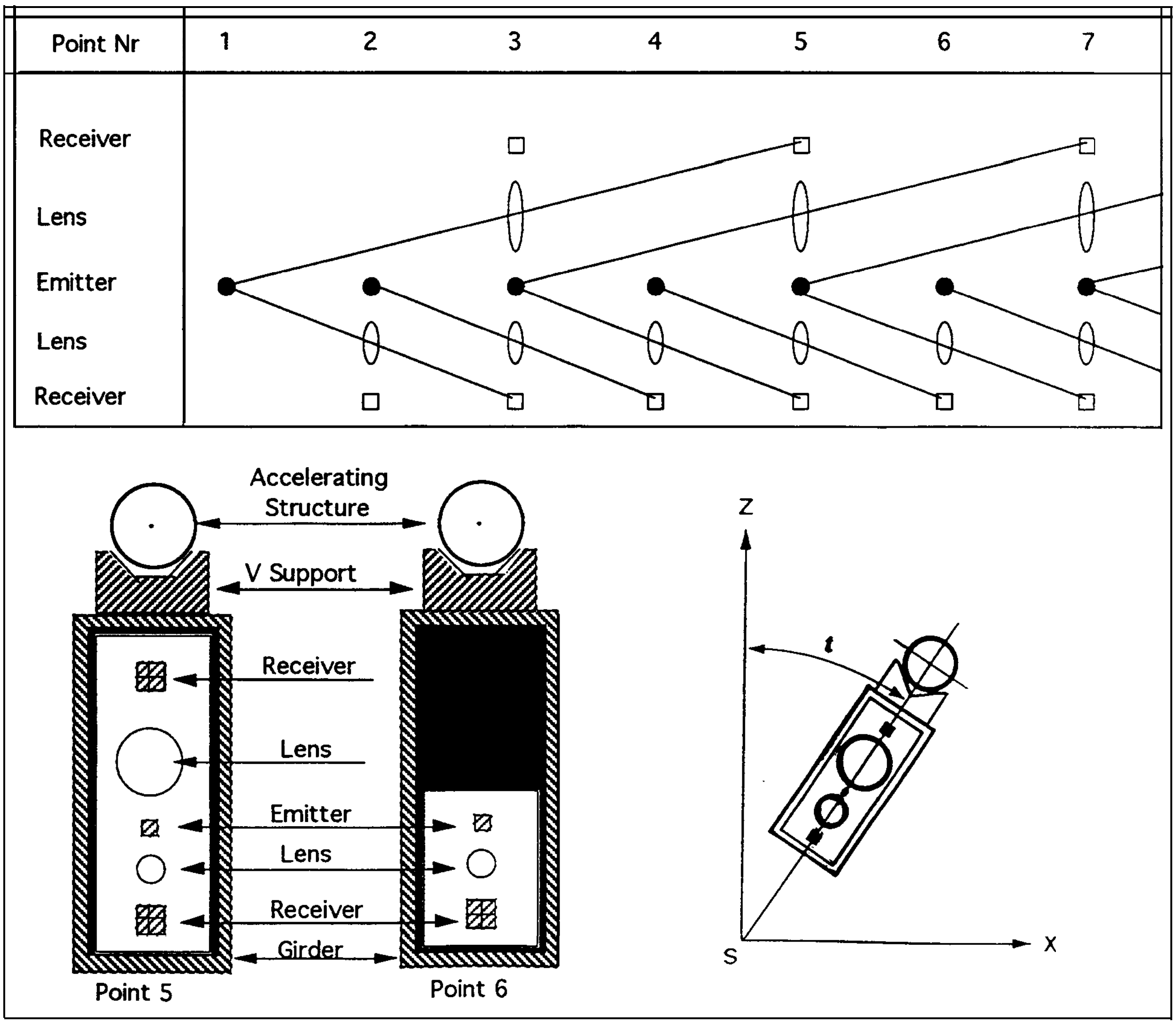
Point Nr
1
2
3
4
5
6
7
Receiver
Lens
Emitter
Lens
Receiver
Accelerating
Structure
V Support
Receiver
Lens
Emitter
Lens
Receiver
Girder
Point 5
Point 6
Z
X
S

Fig. 3

2.1.3 Operation

In measurement with the wire offset measurement device the reference lines overlap and the offset measurements intersect. The same will apply to the optical separation meter. Each point to be measured will be fitted alternately with an emitter, a lens and a receiver. As in the other networks, all the measurements must be made continuously. Each cradle will have to be permanently fitted with the necessary instruments. There will be two types of equipment (figure 3). The optical trajectories pass through the girders. The measurements, shifted by z in relation to the cavities, are made on an axis passing through their centres. Account must therefore be taken of the inclination of this axis. The girders will accordingly be fitted with an inclinometer measuring the angle t in plane ZX. Simulations show that, for a standard deviation of 2 µm on the measurements, error propagation is such that, at the end of 42 modules (59.22 m), the standard deviation on the position of an articulation point would be 0.2 mm. Hence a link with the fine topometry network will be made every 42 modules.

2.1.4 Tests

The instruments were developed by a physics institute (NIKHEF-H) and are used for the automatic monitoring of the alignment of particle detectors in large experimental installations. According to the users, the systems are eminently precise and reliable. To confirm this, four systems were secured to the outside of the two girders of the first test bench. Shifts are made via the actuators and the values obtained at the receivers are compared with those of the linear reference sensors. The results integrate the operational errors of the model and the errors in the reference sensors. For a travel of ± 200 µm, linearity deviations of less than l%, differing slightly for each receiver, are found. The reproducibility of the measurements in any position is better than 2 µm. On the basis of a few significant tests, the constructor certifies that the instrument can be improved and we shall press him to do so.

The new model will very shortly be operating with six girders. Each cradle will be fitted with the components of the optical separation meter. The system will be calibrated in relation to the axis of the cavities or the supporting Vees and tested in actual working conditions.

2.2. External Survey Network

Its purpose is to stiffen the survey system. It will consist of pillar alignment every 21 modules over about 8 km. Statically measured, it will serve as a support for the prealignment phase. It will subsequently be fitted with a continuous measurement system.

2.2.1 Method : Interpolated Biaxial Offset Measurement (fig. 4)

In the plane (V), perpendicular to the line (1,3), the differences between point 2 and the point of intersection I of the line (1,3) and the plane (V) are measured on the abscissa (mx) and the ordinate (mz).

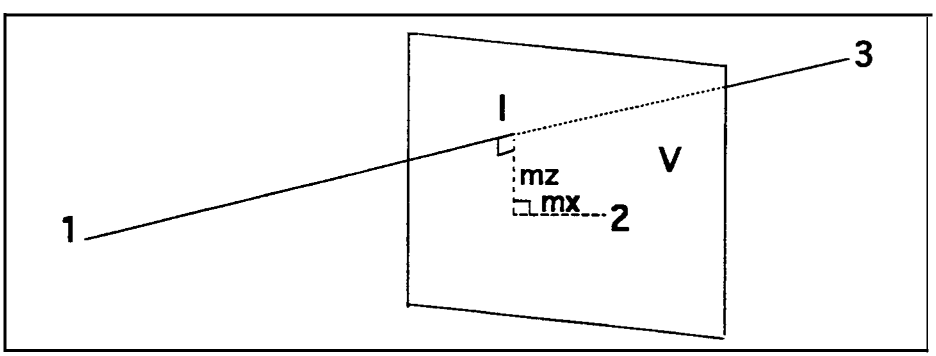

Fig. 4

2.2.2 Instruments

a) Reference line : A carbon fibre is tensioned to slightly below its ultimate tensile stress. The reference line will thus be a curve, theoretically in the form of the *catenary*. As the z measurement depends on the knowledge of this curve, the fibre tension must be especially sophisticated. The system now being studied must be sensitive to a difference of 0.01 N.

b) Wire separation meter: There are several techniques for making a sensor capable of detecting a wire. Developments are under way in various laboratories. Agreement has been reached with them to develop a capacitive method. The variation in the electric capacitance measured between the wire and a reference surface is proportional to the distance variation. A company specialising in this kind of measurement has developed and built a prototype system to our specifications which is now being tested in our laboratory. This system, which takes the form of a hollow parallelepiped open at the ends (4 x 4 x 10 cm) has eight sensors, three on two opposite surfaces and one on the other two. The travel is ±4 mm and, with the wire approximately centred, 1μm of movement corresponds to an output signal of 1.3 mV, meaning that the sensitivity is good. The sensors were specially arranged to provide the greatest possible amount of information on their behaviour during the tests. The final system will probably have two sensors per surface to give a superfluity of linear and angular shift measurements.

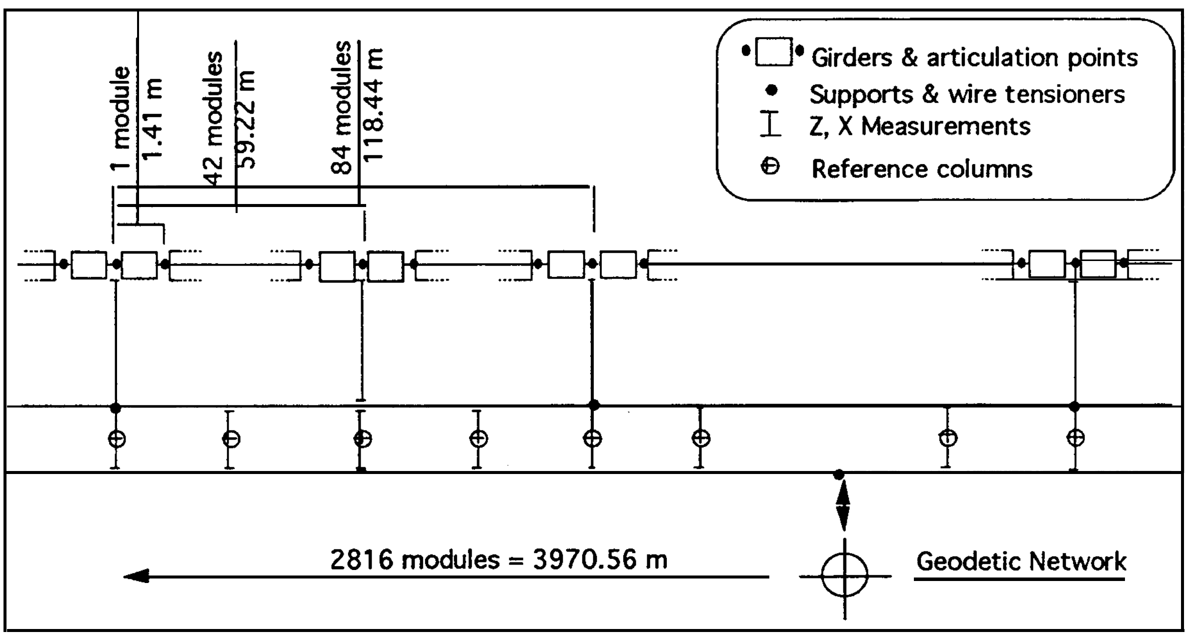

Fig. 5

2.2.3 Operation

In the static determination of a linear wire separation measurement network, the reference line is moved ever closer and the references become alternately supports and measured points. Two parallel reference lines are permanently installed to reproduce it in a continuous network measuring system.

The wires are stretched over a distance corresponding to 84 modules (118.44 m). The distance between the lines depends upon the sensors used; in our case about 10 cm. The wire attachment points are staggered by 42 modules from one line to the other. The attachment points, combined with the tensioning systems, are shared by two consecutive wires. The position of the attachment points of the wires of one line is measured in relation to those of the other. These measurements, plus the distances between the attachment points, strictly determine the figure. The excess of information is obtained by measuring the position of the wires of one line in relation to those of the other at 21 modules from the attachment points (fig.5).

Computer simulations have shown that, in theory, with a standard deviation of 0.01 m on the measurements, the error propagation is such that, at 2816 modules, the standard deviation on the position of a reference would be 2 mm. The geodetic network mesh could therefore be 2816 modules.

2.2.4 Tests

The wire system described above does not yet exist. We do knot know whether it is possible to use it for absolute Z measurements if the geometrical shape of the stretched wire lies within the specified tolerances. Tests are on hand with a 0.32 carbon wire stretched over 120 m. They are also intended for the study of the capacitive sensor system and stretcher support points.

2.3. Geodetic Network

It is possible to handle this network with well-known methods and it has not be specially examined. It would consist of three columns at the ends and the middle of the linacs. These columns will be connected to the precision topometry system. Measurement by spatial surveying will facilitate isolated determinations during the civil engineering and prealignment phases and continuous determinations during the initial alignment phase. It will also be possible to make continuous vertical descent measurements.

3. TEST BENCH N° 2 (fig. 6)

Test bench N° 1 was built to examine the problems linked to the supports and the accurate and automated positioning of the CLIC accelerating cavities. The system developed and commissioned has been fully satisfactory. Its use may be considered for a final solution.

This test bench's performance may be summarised as follows:

- smallest effective movement in any direction : 0.2 μm;
- maximum measured hysteresis for a movement off ±4 mm : 5 μm;
- maximum separation between the intended position and that obtained by dynamic alignment : 0.2 μm.

We now have to examine a method for initial and auto-alignment. Test bench N° 2 is designed to do this.

3.1. Modifications

Test bench N° 2 has six 1.385 m girders. The articulation points are 1.41 m apart. While the principle of the supports and actuators is the same as for bench N° 1, some improvements have been made:

- the positioning precision of the four cavities on the girders is obtained by aligning and adhesively securing ceramic plates to the prealigned metal Vees aligned and stuck to the girders (maximum error: 3 μm);
- the assembly of the mechanical components constituting the link between a girder and the actuators has been replaced by a single piece adjusted in relation to the Vees and adhesively secured to the girder,
- to eliminate the clearance in the ball joints at the heads of the rods the latter are fitted so that, for a girder movement of ± 4 mm, they never pass through the vertical position.

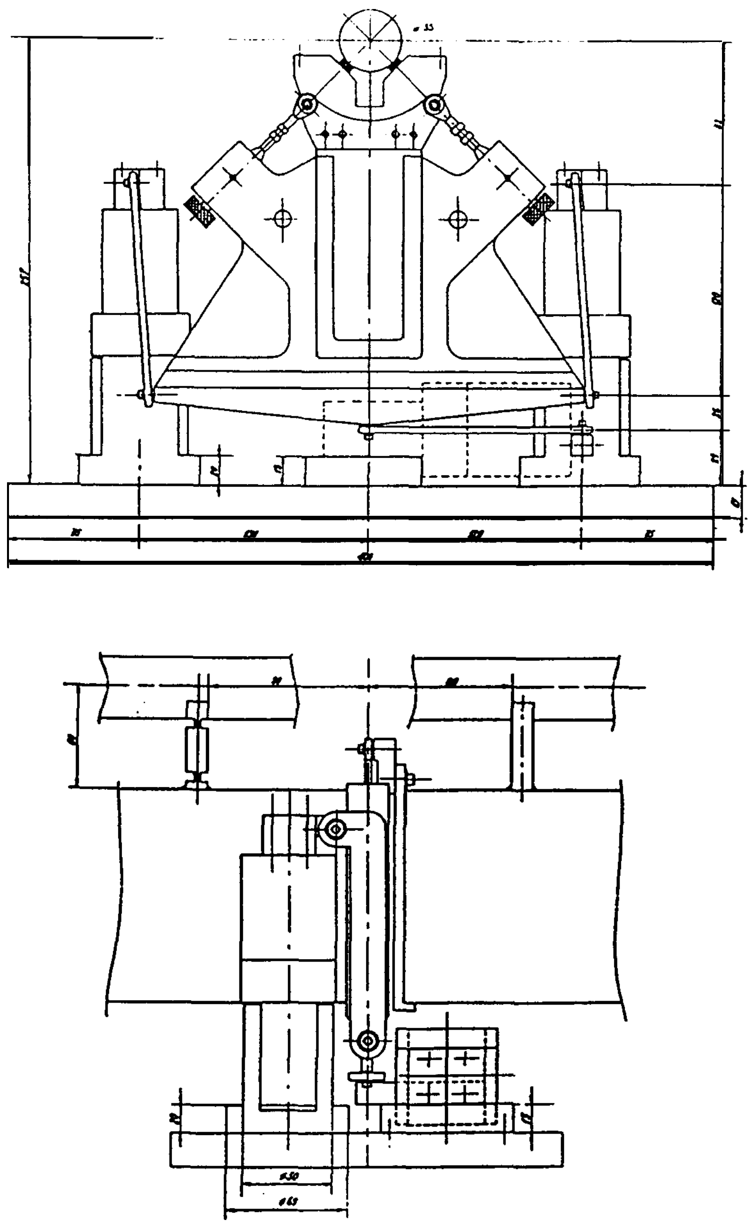

Fig. 6 Cross section and profile vue of the supporting structure of the Main Linac

3.2. Installation

The six girders were fitted by a procedure compatible with that of a real accelerator in a real tunnel.

- Two conventional concrete girders (0.5 x 0.6 x 60 m) were prefabricated and integrated into the experimental tunnel flooring slab. Three threaded rods aligned to within ± 5 mm and secured to each articulation point were fitted on this 12 m long support. These operations took place during the “civil engineering alignment” phase.
- On the threaded rods is laid a metal plate having not only the holes for securing it itself but also the contacts and the holes for pinning and securing the actuators. Each plate is temporarily fitted with a standard SU boring. The plates are aligned to within ± 0.2 mm by the traditional SU methods. The actuators and

the girders are then secured to the plates and hence aligned to within ± 0.2 mm. These operations constitute the pre-alignment phase.

- In order to examine the automatic initial alignment phase, the inside of the girders is fitted with a biaxial optical separation measuring system. It constitutes the internal survey network. The components of this set of instruments are located at each articulation point. The girders are also fitted with an inclinometer. A biaxial wire positioning system (W.P.S.) will shortly be installed parallel to the girders. This will be the external survey network.
- To simulate the phase of auto-alignment with the beam, another biaxial W.P.S. is fitted on each girder at the point provided for the Beam Position Monitor. The wire will represent the beam.
- To monitor the proper conduct of the initial and auto-alignment operations, micrometric sensors are installed along two axes at the articulation points.
- The operations of the initial and auto-alignment phases are remotely controlled. The sensors and actuators are connected to a PC via conditioning electronics.

4. TEST BENCH Nr 2 - TECHNICAL DATA

- Components to be aligned:
  - 6 girders (1385 x 60 x 120 mm) supporting 4 accelerating cavities;

- Actuators:
  - 21 mechanical stepping motors;
  - 18 micrometer stops.

- Detectors:
  - 7 twin-axis optical offset measurement device (Rasnik type);
  - 7 twin-axis wire positioning system (capacitive Fogale);
  - 14 single-axis sensors (Sylvac PL10);
  - 7 single-axis inclinometers (Sensorex JA5L);
  - temperature probes;
  - accelerometers;
  - clock.

- Data processing:
  - Hardware : PC 486;
  - System : UNIX;
  - Programming language: C,
  - Existing software:
    - all the “drivers” for reading out the sensors and controlling the motors;
    - a set of data display software.

- Operation (software to be developed)

  - Initial alignment:
    - a system of sensors secured to the components forms a geometrical reference system
    - the information provided by these sensors is processed by the least square method (existing FORTRAN routine);
    - from the calculated values are deduced the movements to be made on the actuators to align the various components;

  - Auto-alignment (arising from the OPERA program of model N° 1) :
    - the electron beam is simulated by a wire in tension. It may be moved mechanically or electrically;
    - each component is fitted with a wire position detector;
    - all the components must follow the wire movements.