

1. The upper trace shows the current rise in the triplets (about 500 A), while the lower one shows the current in the doublets (about 700 A peak-to-peak). The sweep rate is 5 ms per division.

2. The signal from the wide-band pick-up station which is inversely proportional to the length of the bunches. The first peak corresponds to the beginning of the current rise in the doublets, and the second to the passage through transition. A few rapidly damped oscillations can be seen. The beam intensity is 5.5×10^{12} protons and the sweep rate is 10 ms per division.

3. The instantaneous particle density in a bunch before transition at 3.4 GeV. The sweep rate is 5 ns per division.

4. The instantaneous particle density in the bunch after transition at 9 GeV. The transition energy has dropped to 5.2 GeV using the gamma-transition jump device. The photograph shows that the bunch has successfully passed transition since there are no 'tails' to the trace.

(controlled by the focusing forces). Using the correction quadrupoles installed in the machine, a pulse was transmitted which adjusted the focusing fields so that the value of Q_H rose slowly at first and then dropped sharply, subsequently returning to its normal value. The rate at which the transition region was crossed was limited because Q_H could be varied only within a restricted range to avoid running into resonant phenomena (stop bands).

The method used since August of last year consists in varying the transition energy, again using quadrupoles to adjust focusing fields but this time without changing the value of Q_H . This is called the gamma-transition jump.

Two quadrupoles with opposite polarities are placed half a betatron wavelength apart; such a doublet does not affect the value of Q_H . This arrangement is possible in the PS ring because of a special feature of the CERN accelerator: the ring has fifty periods and, since the normal value of Q_H is 6.25, the two quadrupoles of a doublet can be positioned in straight sections four periods apart. The ring layout now includes four doublets of this kind together with two triplets, which can be regarded as consisting of two adjacent doublets.

The important parameters of the gamma-transition jump are its speed, its magnitude, and its shape, and they have all been closely studied at the PS. With the old Q_H jump system the transition region was crossed about five times faster than without a Q_H jump. With the gamma-transition jump system the transition region is crossed fifty times faster than without it. A new power supply is now being built for the quadrupoles and will make it possible to double this speed during 1974.

With the intensity of 5×10^{12} protons per pulse obtained in November, the

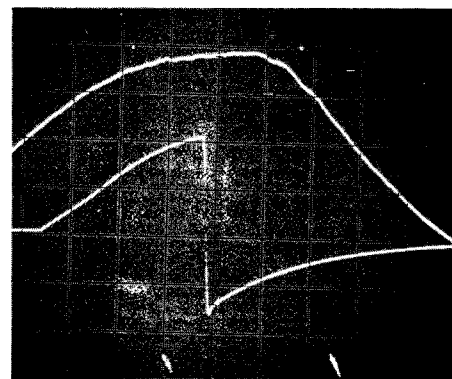
gamma-transition jump system made it possible to maintain the beam emittance (10 mrad) throughout acceleration. With an intensity of 10^{13} ppp which is expected to be reached during the next few years, the space charge phenomena will be even more important at transition and it is intended to enlarge the bunches artificially before transition in order to eliminate transverse expansion. The longitudinal emittance of the beam is then not expected to exceed 14 mrad.

Steering the mole

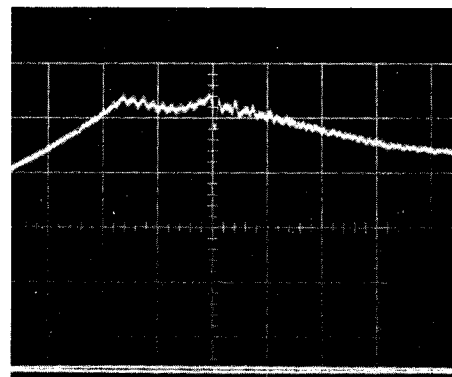
On 12 December, the Robbins boring machine reached shaft PP4 half-way around the 6900 m circumference of the SPS tunnel. Adding the 200 m length of the access tunnel between the Civil Engineering Shaft (PGC) and PP1, the total distance covered in the ten months since the machine descended into the depths is 3650 m.

In accordance with the programme (see vol. 13, p. 70), PP4 is now being used as the servicing shaft instead of PGC — it is from here that the spoil is being removed to the surface and tunnel lining components taken down.

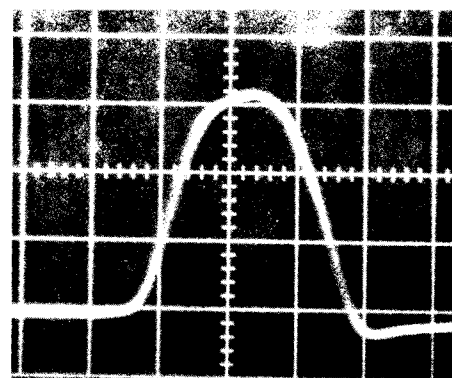
How does the 'mole' know where to go while working several tens of metres underground? First of all, the co-ordinates of the axes of the various shafts had to be determined on the surface, using the CERN survey grid. This was the prime purpose of a surface geodetic network drawn up to an accuracy of 2 mm by triangulation-trilateration. The next step was to mark out the centre of each of the first three shafts (PGC, PP1 and PA2) on the ground. After these shafts had been sunk, the surface co-ordinates were transferred to tunnel level. In this way it was possible to set up 'monuments', accurately sited at the bottom of each of these first three shafts.



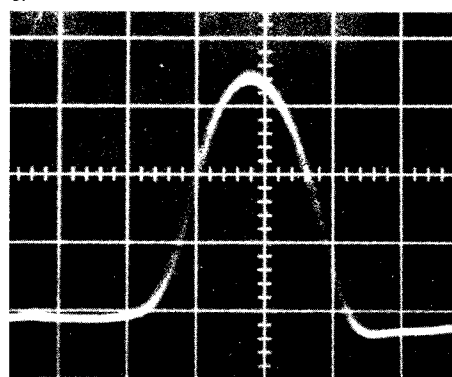
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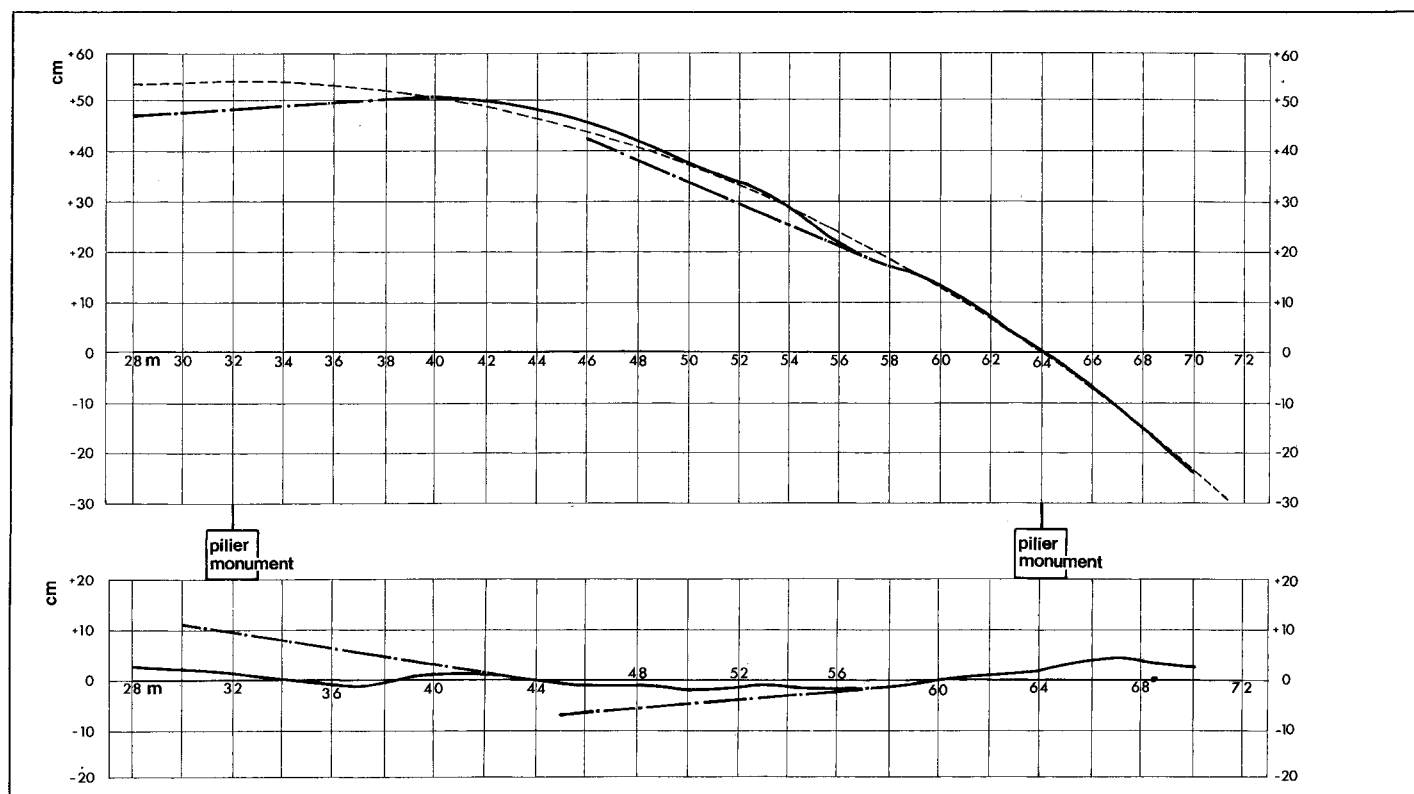
2.



3.



4.



In going from the monument at the bottom of the first shaft to that at the bottom of the second, on the curve laid down in the plans, the following technique was followed: An instrument had to be used which would give a direction in relation to a physical constant and the method employed had to make it possible to position the tunnel in accordance with the requirements of the civil engineering specifications as regards accuracy.

A compass is far from being precise enough. The only possible instrument is a gyro-theodolite, which gives the geographical north to an accuracy of 30 centesimal seconds, obtained at the surface from the datum points of the network. The desired direction, with reference to the geographical north, is measured by the gyro-theodolite on the monument at the bottom of the first shaft. The plotting method consists in setting up a monument every 32 m in the tunnel, gyroscopic measurements being taken at each one.

A straight tunnel some 200 m long was needed for the assembly of the 'mole'. For this reason, the first shaft (PGC) was sunk outside the ring on the axis of the future injection tunnel. An Alpine boring machine began work from there towards PP1 along the line dictated by the gyroscope. When the machine arrived at PP1, it was found that the displacement in relation to the co-ordinates plotted at the surface was 2.3 mm. The 'mole', also guided

by the gyroscope, was started off from the co-ordinates of monument PP1.

The Robbins machine is fitted with two grid targets in known positions with reference to the axis of the machine. The guide datum is a laser beam coming from the monument which gives, in visible form, the direction obtained by gyroscopic measurements. The operator has a guide chart prepared by the CERN Survey Group which has two diagrams relating to a 44 m stretch for excavation. The horizontal plane diagram consists of the track of the laser beam and the theoretical boring curve. The vertical plane diagram is simply a straight line giving both the track of the laser beam and the theoretical excavation curve.

After the first stroke of 1.2 m, the operator checks the position of the head of the Robbins machine. He notes the direction and level displacements of the axes of each target in relation to the point illuminated by the laser beam, transfers them to the two diagrams on the guide chart and deduces the position of the head of the machine. If the location of the head on the diagram lies outside the theoretical curve, the boring axis is corrected.

After it has advanced 44 m, the next survey monument is set up and the 'mole' is given a new direction, dictated by the gyro-theodolite and rendered visible by the laser fitted on this monument. On its arrival at PA2, the

Example of a guide chart for the Robbins boring machine. Top: the Direction diagram (horizontal plane). The X axis, representing the laser beam, carries the longitudinal scale from 28 to 72 m of the monument on which the laser is fitted. On the Y axis are the displacements corresponding to the tunnel curvature. Long and short dashes: theoretical excavation curve; chain dotted line: segments fixing the position of the head in relation to the recorded displacements; unbroken line: real excavation curve in the horizontal plane.

Below: the Level diagram (vertical plane). The X axis is both the theoretical excavation curve and the representation of the laser beam. The broken line: segments fixing the position of the head in relation to the recorded displacements; unbroken line: real excavation curve in the vertical plane.

machine entered an enlarged section previously excavated from the shaft. The polygonal track formed by the 36 monuments set up between PP1 and PA2 had then to be 'closed'. This merely involved relating the PA2 monument, whose exact co-ordinates have been determined from the surface, to all the preceding ones.

The transverse displacement thus found was only 25 mm at PA2, within the limit of 30 mm required in the specification, after a total distance covered of the order of 1150 m. At the next shaft (PA3), the displacement was as little as 20 mm. This accuracy relates only to the direction as given by the surveyor; obviously, the actual tolerances on excavation are less strict but even they do not exceed 7 cm.