CERN-SU/.../p   31 August, 1967

PAPER TO BE PRESENTED AT THE 6TH INTERNATIONAL CONFERENCE ON HIGH ENERGY ACCELERATORS

CAMBRIDGE, Mass.

AUTOMATIC MEASURING DEVICE

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Since 1960 and 1961, when the proton synchrotrons at CERN and in Brookhaven were put into operation, a number of new facts have come to light which have modified the ideas, until then generally admitted as sound for scientific and industrial metrology, of which the alignment of the magnet structure of the accelerators is a direct application.

It was precisely in 1960, after long years of research, that the International Committee of Weights and Measures decided to adopt and to put into practice the new definition of the metre obtained by means of a 86 Kr lamp with hot cathode. Since then the International Bureau of Weights and Measures (B.I.P.M.), and a considerable number of laboratories throughout the world, have continued to study the standard of primary radiation, and the Consultative Committee for the Definition of the Metre (C.C.D.M.) has directed the research work on secondary standards towards the perfecting of particular techniques such as:

- emission of monochromatic radiation by an atomic jet,
- the use of spectral absorption lines,
- the use of interference filters, in particular the Zeeman filters,
- the use of interferential comparators,
- lasers.

The primary standard permits measurements having a relative precision of 10^{-8} to 10^{-9}. Secondary standards are necessary to serve as auxiliaries for the determination of the order of interference, and to maintain the uniformity of the length measurements all over the world. In most measurements, particularly industrial, which outnumber all others, but also in many scientific measurements, a tenth or even a hundredth of this precision is sufficient (10^{-7}). It is possible to attain such an accuracy by means of secondary standards which could be obtained in a simpler manner.

For the metrology of circular accelerator designs under active study, a transfer agent, which permits the above precision to be maintained, must be selected from the available secondary standards. The dimensions of these accelerators have been increased by a factor of 10 compared to those at present in operation, whereas the dimensions of the useful aperture have been reduced, still further reducing the alignment tolerances.

The laser appeared at one time to be that ideal transfer agent, but for scientific and even industrial measurements the laser beam must be used in an evacuated tube. The use of lasers in air remains confined to relatively short distances. The alignment of the Stanford linear accelerator is a special case, in which moreover not all the properties of the laser were made use of, since it served only as a luminous source which was highly directive and very intense; furthermore the pieces to be aligned were very light so that they could be supported by the vacuum tube in which the laser beam was transmitted.

Studies have been made at CERN, aiming at the establishment of the metrological technique to be used for the ISR and the 300 GeV Proton Synchrotron. These researches have developed as follows:

- an ever increasing use of automation,
- full use of computers,
- the design of measuring instruments which, in air, give a precision for industrial use similar to that obtained with measurements in vacuum, the use of evacuated tubes being reserved for very special cases.

These research studies have led to five devices, some of which are still in the prototype stage:

- a laser device for alignment in air up to 50 m,
- in cooperation with the National Physical Laboratory (Teddington), the Mekometer Type III. This apparatus permits the measurement in open air with an automatic compensation for changes of the optical path due to atmospheric conditions. The relative accuracy of the measurement must be better than 10^{-6},
- a system for counting interference fringes at long distances, obtained with a HeNe laser the frequency of which is stabilized. The measurements were carried out in a laboratory in open air. The two mirrors of the interferometer were separated by a distance of 15 m. Over a period of one hour the oscillations of the interference fringes remained within an interval equal to three times the wavelength of the radiation ($\lambda = 0{,}63\ \mu$),
- a prototype of an automatic liquid level making it possible to record level differences of a few microns,
- the construction of an automatic device for length measurements for the alignment of the magnets of the ISR.

This apparatus, called <u>automatic Distinvar</u>, has been conceived to measure rapidly distances between 0 and 55 m. To reach a relative accuracy of 10^{-6} to 10^{-7}, the Distinvar is a part of a unit which consists of:

- a standard consisting of a calibrated invar rule of 4 m, the first metre being subdivided in mm,
- a calibrated bench,
- the transfer element (an invar wire). The wires are calibrated immediately before and after the measurement itself,
- the Distinvar reading head. It is entirely automatic and permits either rapid local readings or transmission of the data directly to the computer. In radioactive areas the measurements can be carried out by means of a robot. It should be noted that the measuring head displays only the difference between the calibrated length and the distance between the supports (range ± 12 mm). (Fig. 1)

The Distinvar consists of a frictionless balance, a micrometric screw of high precision, a carriage sliding on this screw and a measuring head which transmits the information to the computer. The invar wire is attached at one end to this unit and at its other end to a fixed point. The supporting part of the Distinvar and the precision holes in which it rests are machined with an accuracy of a few microns. As the tension applied to the wire is transferred to the measuring points, they have to be sufficiently rigid for the deformation caused by this tension to be negligible.

The invar wire is fitted at its extremities by specially designed elements of attachment to assure a reproducibility of the measurements, to eliminate the effect of axial torsion and to protect it against excessive tension; this is particularly important when the Distinvar is used by means of a robot. (Fig. 2)

The balance beam oscillates between two electric contacts which control the displacement of the carriage by means of the micrometric screw until equilibrium between the tension applied to the wire and the weight attached to the beam is obtained. The sensitivity of the balance and the absence of friction ensure the reproducibility of the measurements. The accuracy is obtained by very careful machining of the micrometric screw and by the use of a precision potentiometer.

The Distinvar measuring head contains a motor-driven 25-turn screw, the displacement of which must be measured and recorded with a precision of 1:2500. Two digitizing methods are possible:

- a direct optical or mechanical shaft encoder producing a parallel coded output number indicative of the shaft angle,
- a potentiometer fed from a constant voltage source, producing an output voltage from the potentiometer arm proportional to the displacement, and digitized by means of a digital voltmeter.

Of the two methods, the latter was chosen for a number of reasons; among them:

- the required precision and resolution is easily achieved in a small package and at a moderate price, whereas direct shaft encoders are 3-5 times bigger, 5-10 times more expensive and difficult to couple to multi-turn shafts,
- the two-wire output from the potentiometer is to be preferred to the 12-20 lead output from a direct digitizer for reasons of transmission economy.

The measuring head contains the reference power supply consisting of a mercury cell and follower amplifier. An accuracy of 0.05% is guaranteed immediately after turn-on and calibration need be checked only after prolonged periods of storage or use.

The output from the Distinvar head can be measured and recorded by any commercial digital voltmeter and printer, tape unit etc. The analog data can, however, also be transmitted to a central computer for immediate analysis. The CERN/ISR system will use one of the general-purpose data trunk cables which will be installed in the ISR complex to provide a direct link between the central computer and all the reference pillars around the accelerator. A light, portable control box will give the survey operator the following possibilities of communication with the computer:

1. Two pairs of decimal switches for identifying the numbers of the reference pillars between which the measurement is being made.
2. A push-button to initiate a recording (enters as a special computer interrupt signal to select, digitize and store the value of the analog signal from the Distinvar unit).
3. A push-button to tell the computer that a series of six measurements has been completed, and to start the computation of errors in those measurements.
4. Two indicator lamps, one lit if the measurements were within tolerance, the other if the measurements have to be repeated.

All control signals to and from the computer go over carrier multiplex signals in the trunk cable (using 1% of the available capacity), and all circuits including the motor and amplifiers in the Distinvar head are powered from a 30 V line in the transmission cable. The cable also provides a telephone link between all operators in the system. The use of these facilities make the measuring equipment easily portable, and each measurement can be completed and recorded centrally in a matter of minutes.

The absolute precision of the apparatus is a function of the precision of the secondary standard, in this instance the 4 m invar rule, calibrated by the International Bureau of Weights and Measures.

The relative precision depends on the reproducibility of the reading apparatus and on the stability of the invar wire, a stability of short duration, as the wire and its reading unit are calibrated immediately before and after the measurement.

In order to know this relative accuracy, one thousand measurements have been carried out on the calibration bench between two sockets fixed on the calibration bench 50 m apart. The measurement data were transmitted to the computer without any intervention of the operators, whose work was limited to installing the apparatus, to attach the invar wire and to vary as much as possible the conditions under which the measurements were carried out.

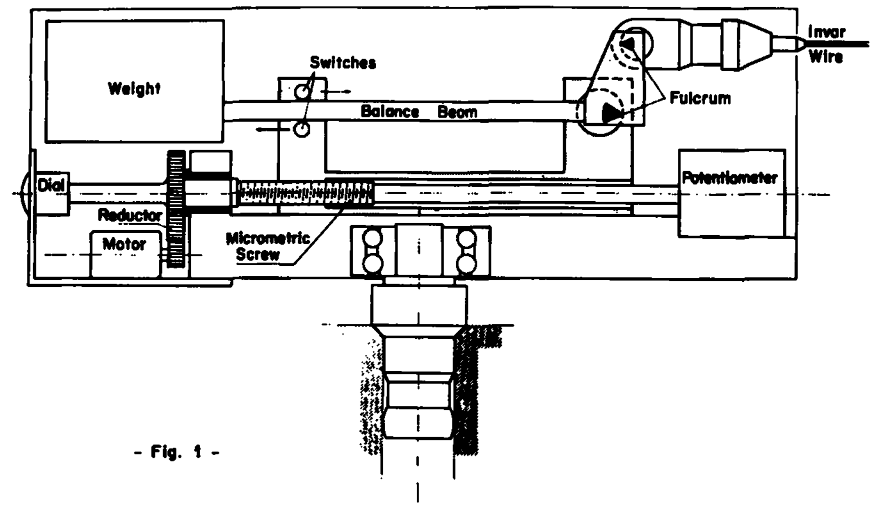
The deviations follow a normal law, and the magnitude of the standard deviation is of the order of 14 microns. In other words, the relative accuracy is situated between 10^{-6} and 10^{-7}.

The geometric alignment of the magnets of the ISR will be carried out in two stages:

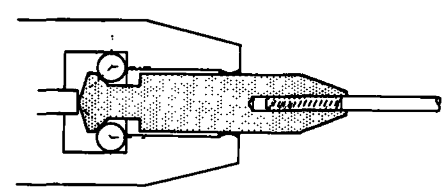
a) Positioning of the reference plates on the pillars, which are distributed at regular intervals along the circumference in a sequence of braced quadrilaterals, completed by distance measurements with the Distinvar.

b) At the interior of a quadrilateral, alignment of magnets by distance measurements with reference to the 4 adjacent pillars.

Due to the precision of the Distinvar, the tolerances of alignment required will be obtained. Because of the speed with which the measurements can be carried out no allocation of time has been claimed in the general planning for these measurements.



- Fig. 1 -



- Fig. 2 -