AUTOMATIC CONTROL AND STABILIZATION OF THE ORSAY LINAC

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Before speaking about automatic control, I would like to show briefly the present status of the Orsay linac. In this initial design the electron linac itself was built by the CSF Company. Since the end of 1961, the laboratory of the Orsay linac has the machine in charge for operating and improvements.

There are now four experimental areas (Fig. 1) available for physics experiments: one at 250 MeV in use since 1960, one at 500 MeV and one at 1 GeV in use since January, 1962, and the last one at 1.3 GeV is just finished now, including the deflecting system. Another experimental area is ready to receive the 500 MeV electron-positron storage ring, but the storage ring itself will be ready in 1965. The positrons will be extracted from a radiator located at the 700 MeV electron energy level and then accelerated from a few MeV to 250 MeV before injection. The electrons will be accelerated from another gun by the last part of the linac and injected in the ring at the same point as the positrons are.

We already accelerated a positron beam extracted at 200 MeV electron energy level. For a 700 MeV positron beam, the ratio of the positron intensity in 3% energy spread to the electron intensity on the target is 10^{-4}.

Now there is another proposal to extend the electron energy from 1.3 to 2.8 GeV by doubling the length of the machine, and to increase the duty factor by a factor of 3, from 50 pps to 150 pps. In this case, the new part of the machine will be built at the front of the present linac, the shielding of the 1.3 GeV experimental area being sufficient for a 3 GeV beam.

Operating a multisection electron linac for physics experiments requires a high stability for both beam current and energy.

It is quite easy to obtain 50% of the beam current in a 1% energy spread, if the transient beam loading is compensated for by early injection or changing the modulator timing.

However, it is difficult to maintain these adjustments over a long period of time, and in addition, the setup time is long unless automatic controls are incorporated.

The influence of variations in the main machine parameters such as High Voltage, Frequency, Temperature, etc., are well known.

It is my intention here to speak only about some of the systems which have improved the Orsay accelerator and some systems which will be incorporated in the machine extension from 1.3 to 2.8 GeV.

I. Klystrons High Voltage

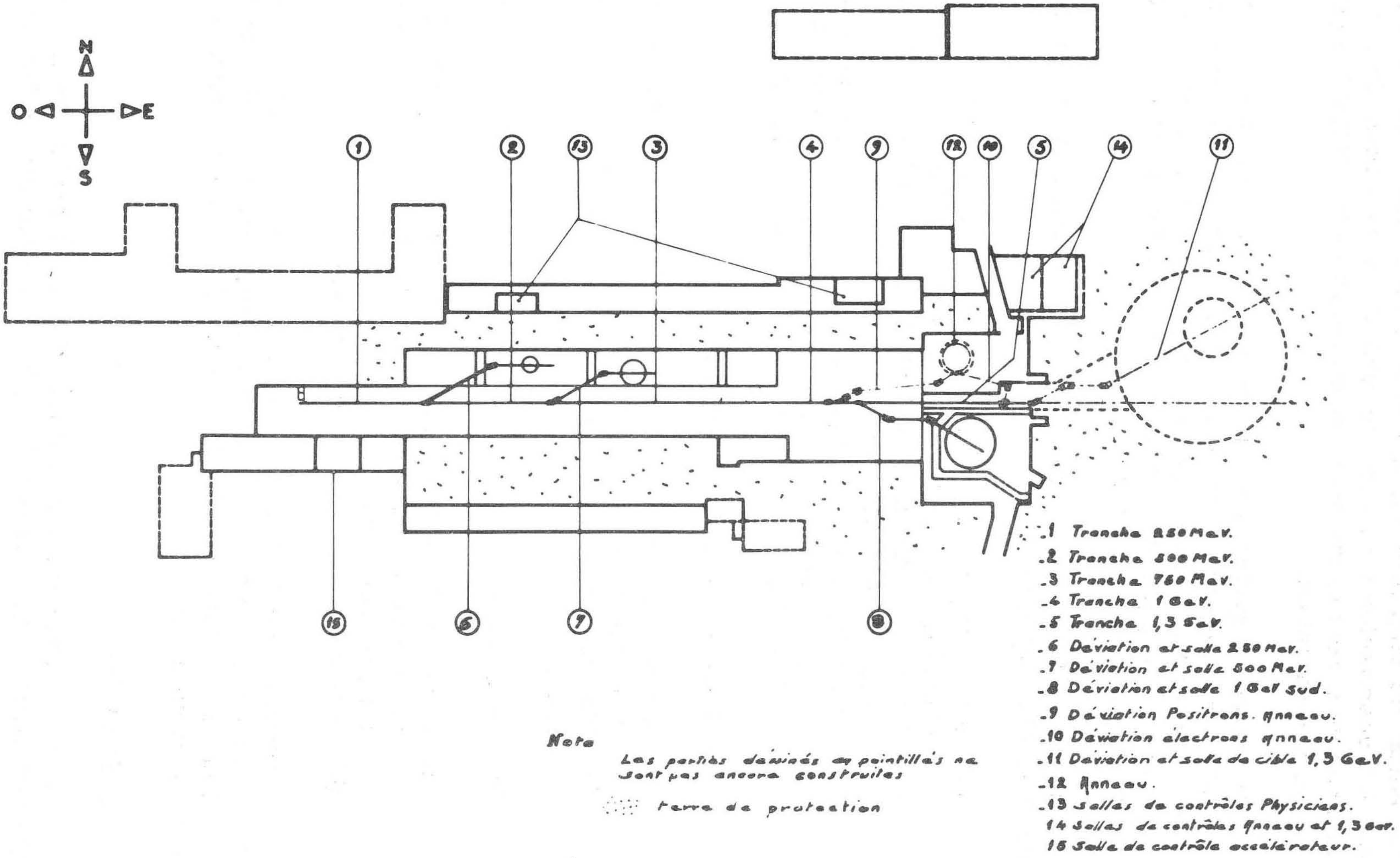
In the initial design, the klystrons and modulators were supplied from a single ac power supply controlled by an induction regulator with a stability of ± 1%. Such a long term stability may be sufficient if the operator can control the long term energy fluctuation. However, with a short term stability of the same magnitude, every fluctuation in the power lines is transmitted to the klystron high voltage resulting in beam energy variations of the same order. With a narrow energy spectrum and energy defining slits, excessive variations in the analyzed beam current result. Furthermore, for the induction regulator which was used, the response to the power lines transients is very slow, of the order of one second, which means that the short term stability was much worse than 1%.

In order to overcome this short term instability, we are now using a motor generator set with an ac voltage regulator of ± 1%. We now get a short term stability better than 0.1% due to the large inertia of the set. Such a system can keep approximately 2×10^{11} electrons/pulse within a 2% energy spread for several hours with current variations less than ± 5%. The long term stability can be further improved by controlling the alternator output not from the ac output voltage but rather from the charging voltage of the pulse-forming network. This means we can also adjust the klystrons high voltage by the inductor of the alternator.

II. Phasing

An automatic phasing system is already installed on five sections, or 300 MeV, of the present accelerator and it is yet working but it is under test too.

The rf phase of the section input signal is compared to the beam phase obtained from a low Q cavity excited by the beam (Fig. 2). The electronic length of the rf comparison circuit is set up so that a null on the phase detector is obtained for the optimum rf phase (Fig. 3). This optimum rf phase is determined by means of a beam energy measurement and fixed by a phase shifter. The phase detector is a magic T with two linear rf diodes (or one diode and a phase wobbling system). The two diode voltages are stretched to a dc voltage and compared in a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.1 Tranche 250 MeV.
.2 Tranche 500 MeV.
.3 Tranche 750 MeV.
.4 Tranche 1 GeV.
.5 Tranche 1,3 GeV.
.6 Déviation et salle 250 MeV.
.7 Déviation et salle 500 MeV.
.8 Déviation et salle 1 GeV sud.
.9 Déviation Positrons. Anneau.
.10 Déviation électrons Anneau.
.11 Déviation et salle de cible 1,3 GeV.
.12 Anneau.
.13 Salles de contrôles Physiciens.
14 Salles de contrôles Anneau et 1,3 GeV.
15 Salle de contrôle accélérateur.
Note
Les parties dessinées en pointillés ne sont pas encore construites
terre de protection

Fig: 1

differential dc amplifier which controls the phase of the rf klystron input. A transmission cavity in one arm of the rf comparison circuit, temperature locked to the section, compensates for small frequency and temperature variations.

With such a system we can control the phase within ± 3° with a range of beam intensity from 20 to 80 mA and a 3 db klystron power range (10 to 20 MW). However, we do not know yet the behavior of the system over a long period of time, let us say for more than one month, without a new energy calibration.

It seems feasible that such a long term stability can be obtained with the following improvements.

(a) Increasing the phase stability of the rf comparison system by choosing rigid and short transmission lines.
(b) Broadening the range of operation to a 10 to 1 variation in the beam current and 6 db for the klystron power.
(c) Achieving a more simple and accurate phase calibration for example, by adjusting the set: Section + Cavity + Rf Comparison Circuit in a separate room set up for this purpose.

The disadvantages of the system are:

(a) A complete system is required yet for each section (cavities, rf comparison circuit, electronic).
(b) We must trust the phase stability of the rf phase comparison system.

The advantages are:

(a) It does not require a special accelerator triggering system nor sections with output couplers, i. e., it can be adapted on the present machine.
(b) It is a continuously operating system.

Assuming the rf driver frequency is stable, there are still two other control systems which must be incorporated if stable and reliable operation of the linac is to be obtained. These are temperature and beam position controls.

III. Temperature

The rf power level in each section is controlled by means of the klystron high voltage and is set to give the optimum performance of

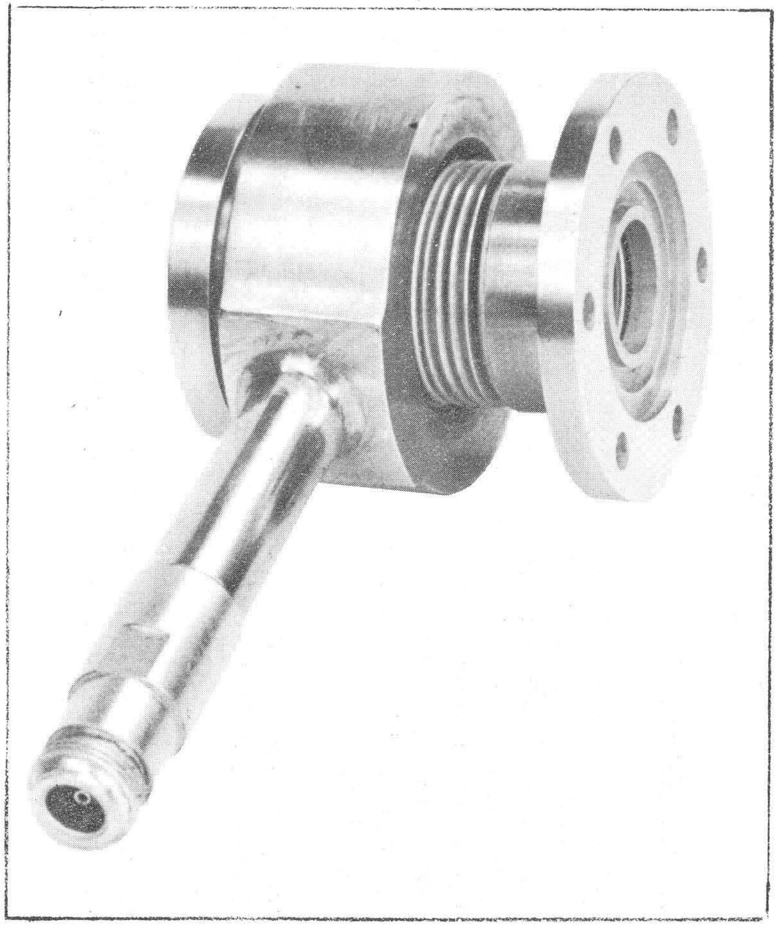
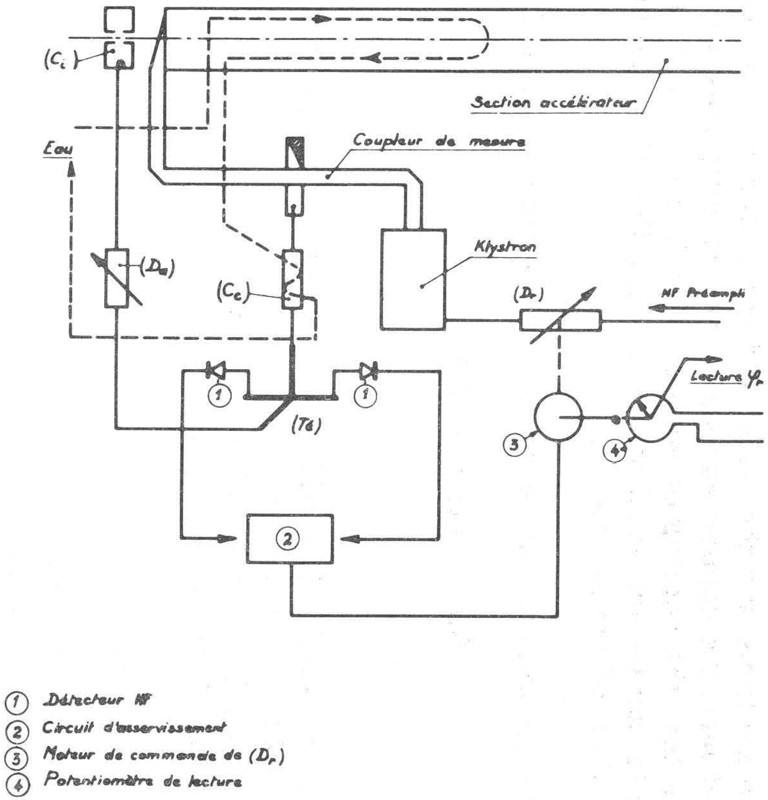


Fig. 2



Réglage automatique des phases hyperfréquence
Schéma synoptique

Fig. 3

section and klystron. Preliminary measurements on the heat transfer between the sections and the water indicated that the temperature gradient between the copper and water is not independent of the power. This means that the cooling of each section has to be independently adjusted. This can be achieved by controlling the rf phase between the input and output of the section.

This comparison can be seen to be extremely sensitive, since

$$\Delta\phi = \alpha\omega\tau \cdot \Delta\theta$$

where

α is the coefficient of linear expansion of copper
ω is 2π x frequency
τ is the filling time of the section
$\Delta\theta$ is the temperature change

For example, with

$\omega = 2\pi \times 3 \times 10^{9}$
$\tau = 10^{-6}$ seconds
$\alpha = 1.6 \times 10^{-5}$

$$\underline{\Delta\phi = 17 \text{ degrees/degree C.}}$$

IV. Beam Position Control

For a high power beam, it is very important to keep the beam on the axis. A steering system which is really independent of energy and stray magnetic fields appears difficult to build. However, for a single beam operation it should be possible to use an error signal derived from a beam position monitor to control steering dipoles and keep the beam on axis; after phasing a given sector, the beam can be steered and the position monitored. This sequence of events is then carried out on each successive sector.

Despite the multiplicity of parameters affecting the beam dynamics, it should be possible to design in such a way an automatic beam steering system.

In this stage we still prefer to put local control loops, better than a central computer, and to increase the stability of the components.

In conclusion, at Orsay the present philosophy is always to manually control the accelerator with the exception of the automatic systems which I have described.

BLEWETT: Could you give an estimate of the ultimate that you could achieve in the control of phase?

BURNOD: With the electronics which we have now, because we use a mechanical phase shifter, we think that ± 3° is a limit we cannot improve. If we use a ferrite phase shifter instead of a mechanical one, we can have a continuous variation of the phase and a better short-term stability, but of course using such a ferrite device we will lose in long-term stability due to the ferrite and its power supply.

JAMESON: What kind of short-term phase stability are you talking about?

BURNOD: Oh, the phase stability is now ± 3° over several hours. There is no problem for the short-term stability using a mechanical phase shifter.

FEATHERSTONE: Must you control the temperature of the transmission lines which bring the phase information to your control devices?

BURNOD: It is not done yet, but we must do it.