DESIGN CONSIDERATIONS, CONSTRUCTION AND PERFORMANCE OF A SLED-TYPE RADIOFREQUENCY PULSE COMPRESSOR USING VERY HIGH Q CYLINDRICAL CAVITIES

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Summary

LIPS (LEP Injector Power Saver) is the implementation of a SLED [1] type pulse compressor for the LEP electron linacs at CERN. The reasons for choosing a resonator type with inherently higher Q (as compared to SLED) are discussed. Possible alternatives are larger cylindrical resonators and non-cylindrical (f.e. spherical) ones. After extensive investigations including the building of a working model, spherical resonators were abandoned in favour of cylinders using an H 0 3 8 (TE 0 3 8) resonance with an inherent Q factor of over 200000. Methods had to be developed for coupling to the feed waveguides, tuning of the resonators and suppression of unwanted resonant modes. Results of the practical tests and operation are presented.

Introduction: General design considerations

In the early stages of the LIL project [1], it was studied whether the SLED principle [2] could be used to reduce the number of klystron/modulator stations by equipping some of the klystrons with such a pulse compressor and doubling the number of accelerating sections connected to such a station.

First theoretical investigations were encouraging, but they showed as well that the boundary conditions for applying this principle were, to a certain extent, more stringent than in the case of the "original" SLED. In particular, it had to be made sure that an energy multiplication factor of more than $\sqrt{2}$ was achieved, due to the splitting of the power. Therefore, a quality factor > 150000 seemed desirable.

An extensive search for resonators with an intrinsicly higher quality factor was undertaken. Since, for "similar" resonances, the quality factor is determined, to a large extent, by the volume to surface ratio of the resonator, the investigations first focused on spherical cavities [3]. In fact, the idea was persued up to and including the building of a working model [4].

Based on the experience gained with this model (on low RF levels as well as with high power), it was felt that these resonators were unsuitable even for a small series production: The suppression of parasitic modes proved to be extremely critical.

Therefore, we went back to investigating cylindrical resonators further. The problem, of course, is not to find a resonant mode with a sufficiently high Q factor (this can be achieved in any case by making the resonator large enough and admitting a very high order mode) but to find such a mode which is far enough away from others.

The search was restricted to H 0 m n (TE 0 m n) modes because modes which are not azimuth-invariant may split up into many quasi-degenerate modes with resonant frequencies very near to each other, depending on imperfections of the resonator. Figure 1 shows a typical example of the mode charts which were produced during this mode search. The axial and radial dimensions of the resonator were varied at the same time, as to keep the frequency of the wanted mode (in the particular case, H 0 3 8) constant, whereas all other resonant frequencies (with the

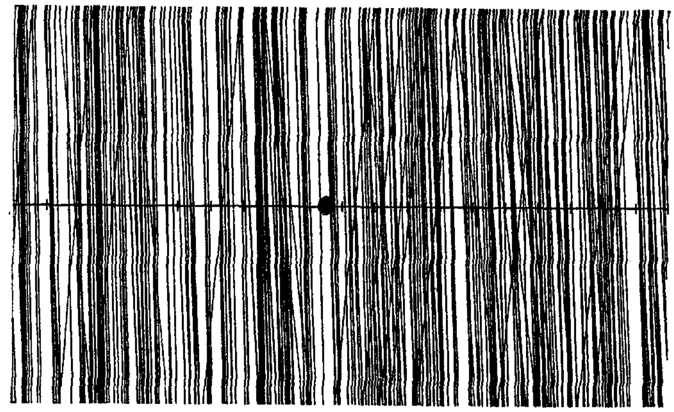

Fig. 1
Mode chart for H 0 3 8 at 2998.55 MHz
Horizontal scale: diameter from 35 to 55 cm
Vertical scale: frequency from 2988.55 to 3008.55 MHz
LIPS marked with a circle ●

exception of E 1 3 8, to be precise) vary and produce traces across the chart. Most of these parasitic modes show a decrease of their resonant frequency with an increase of the cylinder diameter (the cylinder becoming more oblate). Several tens of meters of such mode strips were produced and inspected for places where the wanted mode is isolated.

Many "interesting cases" were identified and studied in this way. Finally, the H 0 3 8 mode was chosen. As it was necessary and intended to detune the E 1 3 8 mode (which is "naturally degenerate" with the wanted mode in an undisturbed cylinder) by a circular groove near one of the endplates (a method as well used for SLED), the effect of such a groove on the other modes near to the wanted frequency was calculated by a disturbance method. This led to a small modification of the dimensions.

A close-up of the mode chart for the dimensions which were finally chosen is shown in Fig. 2.

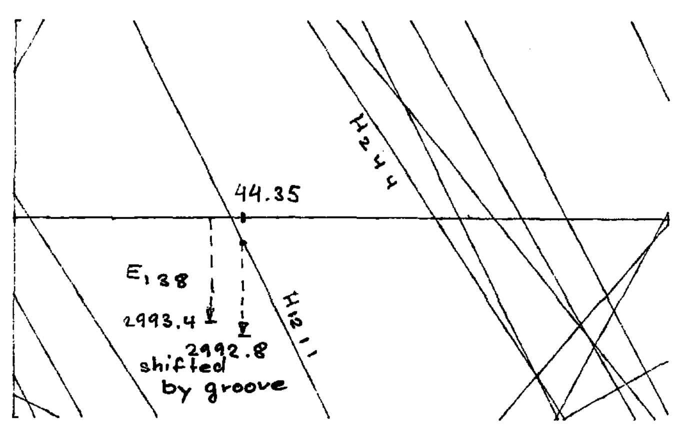

Fig. 2
Investigated mode: H 0 3 8 at 2998.55 MHz
Vertical scale from 2988.55 to 3008.55 MHz
Horizontal scale from 44.00 to 45.00 cm

Principal geometrical and electrical data of the resonators are given in Table 1.

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Table 1

Diameter	44.35 cm
Length	58.5 cm
Diameter of tuning piston	16.7 cm
Displacement	10 mm
Diameter of coupling holes	28.5 mm
Distance from cylinder axis	34.7 mm
Working frequency	2998.55 MHz
Resonance type	H 0 3 8
Cavity Q - theoretical	207000
measured	180000
Coupling factor β	9...11

Mechanical resonator design and construction

For reasons of economy, the cylinders and the outer part of the endplate containing the tuner were made out of soft iron copper-plated on the inside. The endplates are bolted to the cylinders, using aluminium wire joints. The tuner piston is made out of solid copper. The coupling endplate was made out of an outer stainless steel part brazed to a copper central piece comprising the waveguide connection pieces. The copper-plating was specified to be rather thick - 40 micrometers on the soft iron parts, 10 micrometers on the stainless steel as compared to the skin depth of about one micrometer - in order to avoid thermal stresses in the boundary between copper and iron: The periodic heating of the surface due to RF losses was calculated to cause instantaneous temperature variations up to 13° C. The measured values for the quality factor were between 170000 and 180000, as compared to the theoretical value of 207000 (for ideal copper surfaces).

Tuning and coupling

Tuning was provided by a non-contacting piston in the endplate opposite to the feeding side. Its diameter corresponds to the place of the first current zero on the endplate, hence there are no (legal) currents parallel to or across the slit around the plunger. A mechanical movement of 10 millimeters yielded a tuning range of 10 MHz. The coupling was done via the sidewalls of the feeding waveguides by two holes in a half-wavelength distance to each other, one of the holes being a quarter-wave length off the short-circuited end of the waveguide. This coupling offered the advantage that only such resonance modes can be excited whose fields are, at 180 degrees azimuthal distance, in opposite direction, yielding a further protection against parasitic modes. A fringe benefit of this configuration is that, by moving the short-circuit of the waveguide, the coupling factor can be varied. This proved to be rather useful during the laboratory tests, and it may be, at a later moment, incorporated into an experimental version to be used on the accelerator.

Cooling and vacuum

The setup is water-cooled with cooling pipes being brazed to the outside. Pumping flanges were installed at half height on the cylinder surfaces. RF shielding was done by a grid with azimuthal slots in the wall and by an additional baffle in the pumping duct.

The mechanical setup of one of the LIPS is shown in a photograph (Fig. 3).

Unlike as at SLAC (before the sub-booster klystrons), the amplitude and phase-switching had to be done before the inputs of the high-power klystrons at a power level of some hundred watts. While, in the

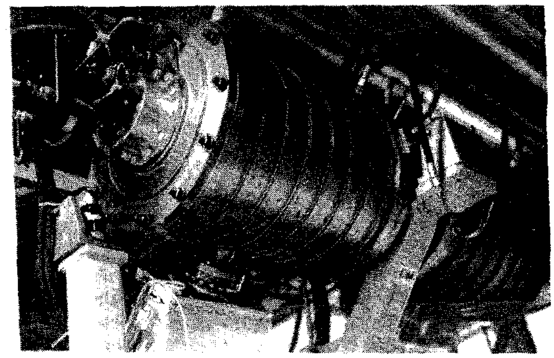

Fig. 3

Associated low-level electronics

first instance, it seemed a trivial problem to obtain PIN amplitude and phase switches having the required specifications ("hot" switching, switching time < 100 nanoseconds), the problem was, in fact, very difficult to solve. Very extensive market research finally showed one supplier who was willing and able to furnish such devices. First prototypes worked quite well for some time, and then continued to break down for reasons which are not yet all properly understood. On request, the manufacturer modified the design for higher power on the expense of longer switching time.

Calculated input and output pulse characteristics

The fact that the phase switching time of the PIN devices was not as short as originally hoped led to calculations which were slightly modified with respect to the formulae used by SLAC [1]. The forms of the input and output pulses as well as the resulting energy multiplication factor are given in Figs. 4 and 5. Detailed derivation of the formulae used is given

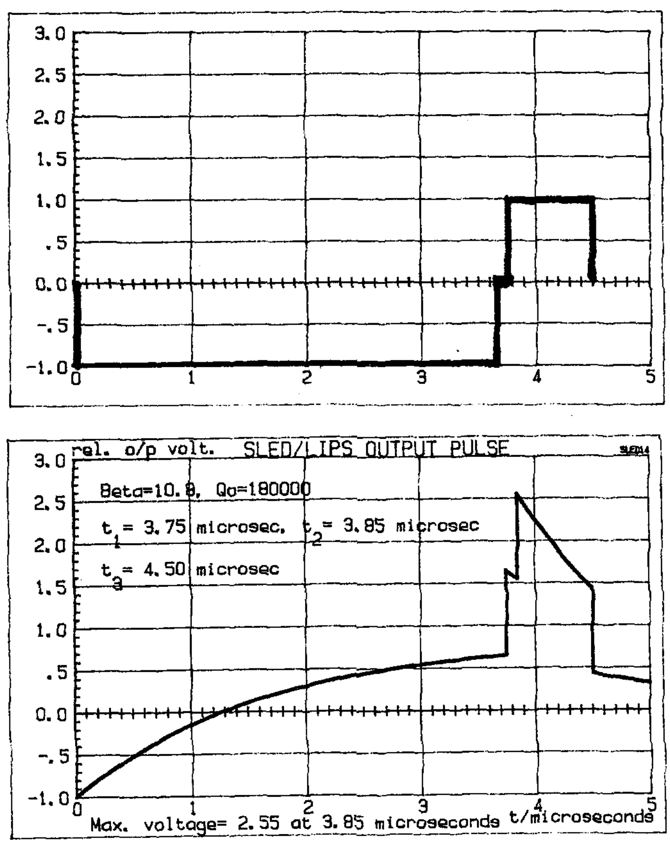

Fig. 4
Form of input and output pulses

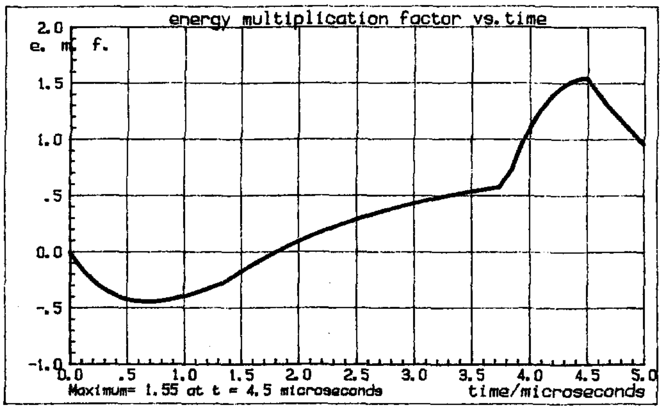

Fig. 5
Energy multiplication factor versus time

in [6]. A remarkable result is that the maximum energy multiplication factor occurs considerably earlier than one (acceleration section) filling time after the phase inversion, and that the optimum pulse length after inversion is shorter than the filling time. This means, by the way, that the present acceleration sections are rather poorly matched to LIPSified operation, because about one quarter of the length of the section is virtually field-free when the electron beam passes. This field distribution on the section is shown in Fig. 6.

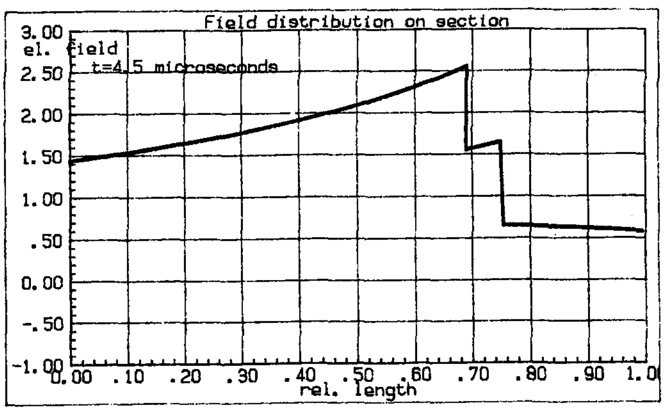

Fig. 6
Field distribution on the accelerating section

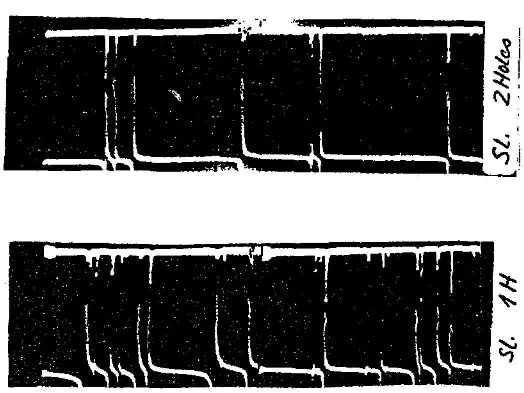

Fig. 7
Spectrum of resonator, coupling via 2 holes (upper photograph) and 1 hole (lower photograph) sweep 100 MHz

Tuning and running-in

The spectrum of one of the resonators, as measured with a network analyser, is given in Fig. 7, showing that the nearest parasitic modes are about 15 MHz off.

To achieve proper functioning with full klystron output power (about 30 MW peak) took a couple of days for the first two LIPSes which were put in operation. Figure 8 shows the form of the output signal. The absence of ringing at the beginning and the end of the pulse and after the phase inversion indicates that the perturbation due to parasitic modes is negligible.

The third LIPS was tried to degas by warming the setup with hot water and pumping. Thus it took only about one working day to get it up to full power.

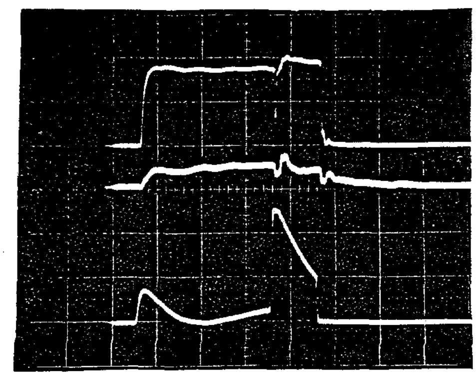

Fig. 8
Form of input signal (upper trace), reflection (center) and output signal of LIPS, Peak output 150 MW

Possible developments

Further investigations using a "spare" LIPS setup may consist in trying to optimize the coupling and to try driving only two sections with a LIPSified klystron. Also, it may be studied whether it is worthwhile to develop sections which are more suitable for SLED form RF pulses.

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