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October 1, 1968

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ABSTRACT

A progress report is presented on the activities at LRL in connection with electron-ring accelerators. A two-stage compressor unit (employing only low-intensity beams) has been built, and operated with a 4-MeV 100-mA linac as an injector. Electron rings have been formed and compressed from 20 cm radius to 7 cm radius. A three-stage compression unit has been constructed and is now under test with the high intensity (200 A) 3.3-MeV beam of the Astron injector. The apparatus is described. Design work on a magnetic expansion unit is reported.

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INTRODUCTION

The major effort of the LRL electron-ring accelerator group, since its creation in January 1968, has been devoted to the design, construction, and operation of two electron ring compressors, and to a design study of magnetic expansion units. Other aspects of the program (not described here) include design studies on electric acceleration columns, experimental studies of the firing of spark gaps by lasers (relevant to a pulsed-gap acceleration scheme), and theoretical studies that include stability analyses and calculations on radiation into cavities.

I. COMPRESSOR I

The basic parameters and general description of this compressor have been given in Ref. 1, p. 89 ff. This two-compression-stage bell-jar device was built to obtain experience in design, fabrication, diagnostics, and operation. The repetition rate was less than one per minute, and the beam currents very low; it was operated with a 4-MeV 100-mA linac, having an energy spread of 15%, as an injector. Figure 1 shows the compressor with one side open.

An electromagnetic chopper and trim coil system selected a 20-nanosecond electron burst from the 4- μ sec linac pulse. The electrons were injected into the compressor when the magnetic field was 750 G and while a set of inflector coils (with a 20-nsec current decay) temporarily depressed the strength of the confining field. The decrease in radius of the ring with time was measured with a movable scintillator, whose signals correlated with those observed on a x-ray detector. The results

were in agreement with the compression calculations. If two sets of coils were used the ring was contained for several msec, returning to the outside radius as the coil currents decayed.

The minor radius of the rings was determined to be roughly several millimeters (part way through compression), as measured by an axial beam clipper and by observing the duration of x-ray pulses generated when the rings were compressed onto an obstructing probe. Trapping efficiency was only approximately determined, and found to be in the range of 1% to 10%. An experiment with an axially movable obstacle indicated some axial spreading of the beam. No evidence of enhanced radiation at the cyclotron frequency or instability-induced losses was observed.

The primary benefit of Compressor I was the experience gained, which was subsequently employed in the development of Compressor II.

II. COMPRESSOR II

This is a considerably more sophisticated device than Compressor I. It is a three-stage compression unit built to high vacuum requirements and capable of operating with large beam currents, at a repetition rate of about one per second. The apparatus is now under test. Figure 2 shows a view of the compressor when partly assembled, and Fig. 3 is an overview of the compressor assembled in the Astron experimental area.

1. Constructional Features

The compressor vacuum chamber was fabricated (commercially) of alumina, whose high strength, nonconductivity, and good vacuum properties are consistent with a design that employs external coils. A 500-Å-thick nickel conducting layer was evaporated on the inner surface of the vacuum

chamber. To prevent shock loads, the vacuum-chamber supports and the coil supports are separate. Both are constructed from laminated epoxy and glass cloth. The coils were manufactured of square hollow copper conductors, vacuum-potted in epoxy. Digital computation of fields and particle properties was used to determine the appropriate parameters of the three coil pairs.

The compressor is designed to operate in the 10^{-8} -Torr pressure region. It is vacuum-isolated from the Astron injector by foils. Two 500- ℓ /sec getter ion pumps brought it to 5×10^{-8} Torr in one week, under experimental conditions.

2. Coil Circuitry

The three coils are energized in sequence from three condenser banks; the current rises sinusoidally and the circuits are crowbarred at peak current. For the third coil the peak current can be held constant within a 3% range for 3 msec by a power crowbar.²

3. Beam Transport to the Compressor

The transport line from the linear induction accelerator is roughly 11 m long and contains an emittance measurement box, beam current and position monitors, a pulse chopper, and appropriate steering and focusing elements to match the beam into the compressor. The locations and currents of the beam focusing elements were determined by digital computations, in which both emittance and space-charge effects were included.

The emittance box permitted, via TV observation, rapid tuning of the accelerator beam to maximum brightness (rather than maximum current). Under good conditions, more than 200 A, at 3.3 MeV, is available in a (single-plane) emittance area of 0.17 cm radius.

The chopper deflected a 20-nsec pulse, out of the 250-nsec Astron pulse, and let it travel (on a straight path) through an opening in a 2-m concrete wall into the experimental area.

4. Injection and Capture

Beam is injected into the compressor at a radius of 21.4 cm, through a soft iron shield tube of 0.04-in. wall thickness, which has been copper-plated with a thickness distribution (0.002 to 0.008 in.) such as to minimize its perturbing effect on the magnetic field at the instant of injection.

The beam is captured by an inflector system which uses a spark-gap-switched pulse line to produce a 40-gauss field perturbation, over 240 deg of the orbit, with a decay time of 20 nsec. The closed orbit at injection is given a maximum displacement of 2.4 cm, which is decreased while beam is injected, and in this manner a few turns are captured.

5. Puff Valve

Injection of gas into the compressor, for studies of ring loading, is controlled by a puff valve.³ A rod with a conical seat 7.5 cm from the median plane of the compressor is magnetically pulsed by a coil at its far end to open a 1-mm³ storage volume. Pressure rise times less than 100 μ sec are obtainable.

6. Diagnostics

Within the compressor are two sets of shielded (and air cooled) Faraday cups mounted in pairs (so as to give information on beam axial position). One set, located just at the beam entrance (0 deg), is remotely retractable; the other is fixed at 330 deg and detects uninflected beam.

Remotely controlled insulated tantalum flags serve as beam probes, crude Faraday cups, and x-ray signal sources.

External to the vacuum chamber are shielded photomultipliers with scintillator buttons for x-ray detection. Also external are three sets of magnetic field pickup loops, which should serve as accurate monitors of circulating beam current. Enhanced radiation at the cyclotron and betatron frequencies (and various harmonics and beat frequencies) can be detected by pickup loops, capacity probes, and a helical antenna.

An image converter camera, with a telescope, is capable of photographing the beam (after compression) by its synchrotron light. Intervals between pictures can be varied from zero (a continuous, streaking sequence of pictures), to 500 μ sec. Exposure time can be varied from 100 nsec to 500 μ sec. A K-band microwave detector monitors synchrotron radiation of lower frequency.

General beam loss in the area is detected by an x-ray pinhole camera.

III. DESIGN STUDIES

The further experimental program is not precisely defined, but awaits experimental results from Compressor II. Design studies have been in two general directions:

1. Compressor II A. The concept here is to make relatively minor changes in Compressor II that permit the experimental study of a situation in which the guide-field axial focusing force on a stationary ring is reduced to zero. This might be accomplished by a small centrally located coil placed within the electron ring, which would permit study of ion and image focusing, including the influence of various wall materials.

2. Compressor-Expander III. This is a compressor with the feature of being able to expel the ring into a magnetic expansion unit. The compressor parameters would be very close to those of Compressor II (so as to maximize the re-use of components), but advantage would be taken of experience gained in the first experiments and the improved capabilities of the new Astron injector (scheduled for completion in late 1968).

The design and construction of a magnetic acceleration unit is a delicate procedure, for the radial magnetic field must be kept at a value less than a few gauss over a distance which is as long as possible. Using digital computation, possible parameters have been derived for a three-coil-pair system. The inner compressor coil (pair #3) is asymmetric, with coil #3A being relatively short and the opposite coil #3B being 1 meter long. Figure 4a shows a possible circuit, in which, after coil pairs 1 and 2 have been fired and crowbarred, switch S31 is closed so as to complete the compression process. Subsequently, switches S32 and S41 are closed, which causes the current in coil #3A to increase and that in coil #3B to decrease. With proper choice of L31 (which primarily controls the current imbalance in coil pair 3) and of M_{41} and M_{42} (which control the final currents in coils 1 and 2), the fields become such as to move the ring adiabatically into the solenoid while simultaneously decreasing the guide-field external focusing on the ring. At an appropriate point the ring "spills out" and accelerates (at an adequately low rate). Figure 4b shows the current wave forms for a possible set of circuit parameters.

ACKNOWLEDGMENTS

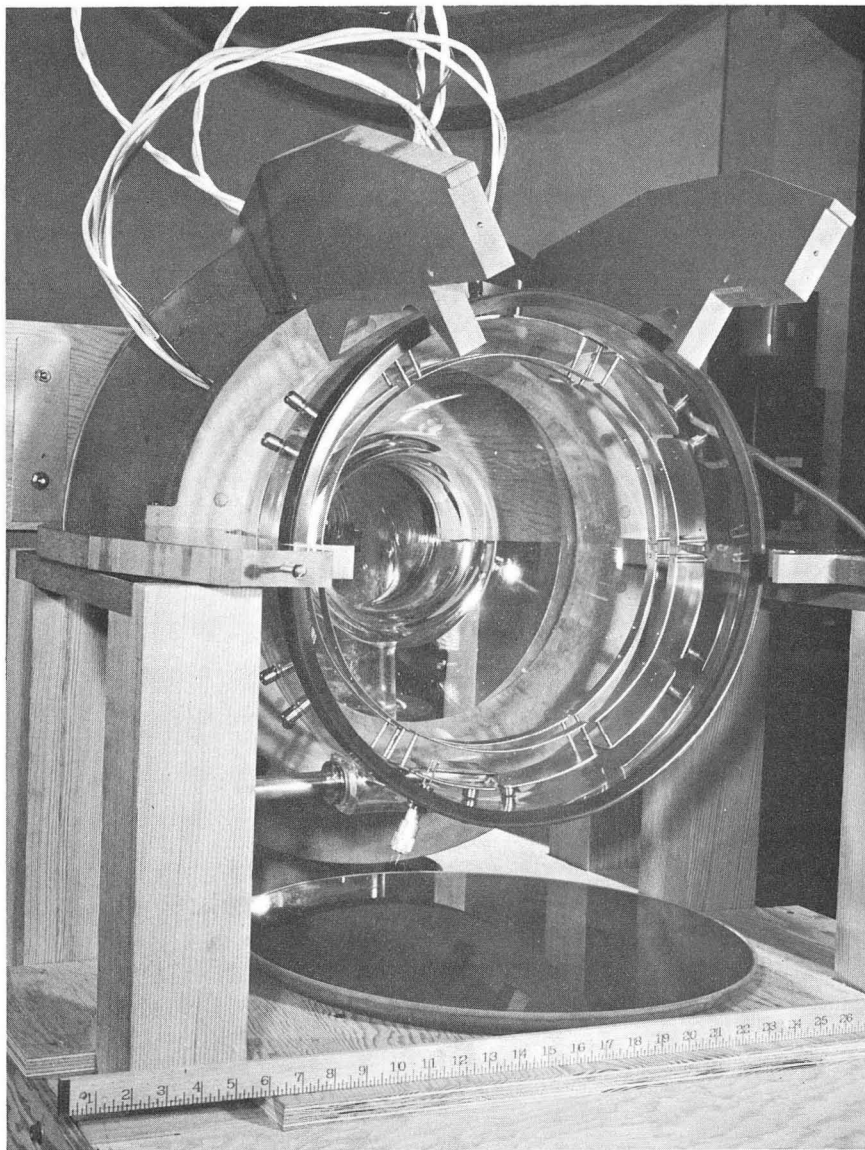
The authors are indebted to many colleagues, whose hard work and encouragement has been a continuing source of inspiration and strength. It is not possible to name all the scientists and technicians whose untiring efforts have gone into the work reported here, but the authors wish especially to express their gratitude and thanks to L. Biagi, D. Bliss, W. Carpender, J. Colonias, A. Faltens, W. Gagnon, J. Greer, J. Hauptman, H. Hausman, D. Hopkins, C. Kerns, R. Kilpatrick, B. Levine, J. Meneghetti, M. Moebus, D. Paxson, C. Pike, J. Rechen, R. Reimers. The cooperation of our colleagues at IRL, Livermore: J. Beal, N. Christofilos, R. Hester, C. Hurley, D. Kippenhan, W. Lamb, L. Simpson, and the Astron operating staff is gratefully acknowledged. The sensitive and helpful guidance of E. M. McMillan, C. M. Van Atta, and E. J. Lofgren is most appreciatively acknowledged.

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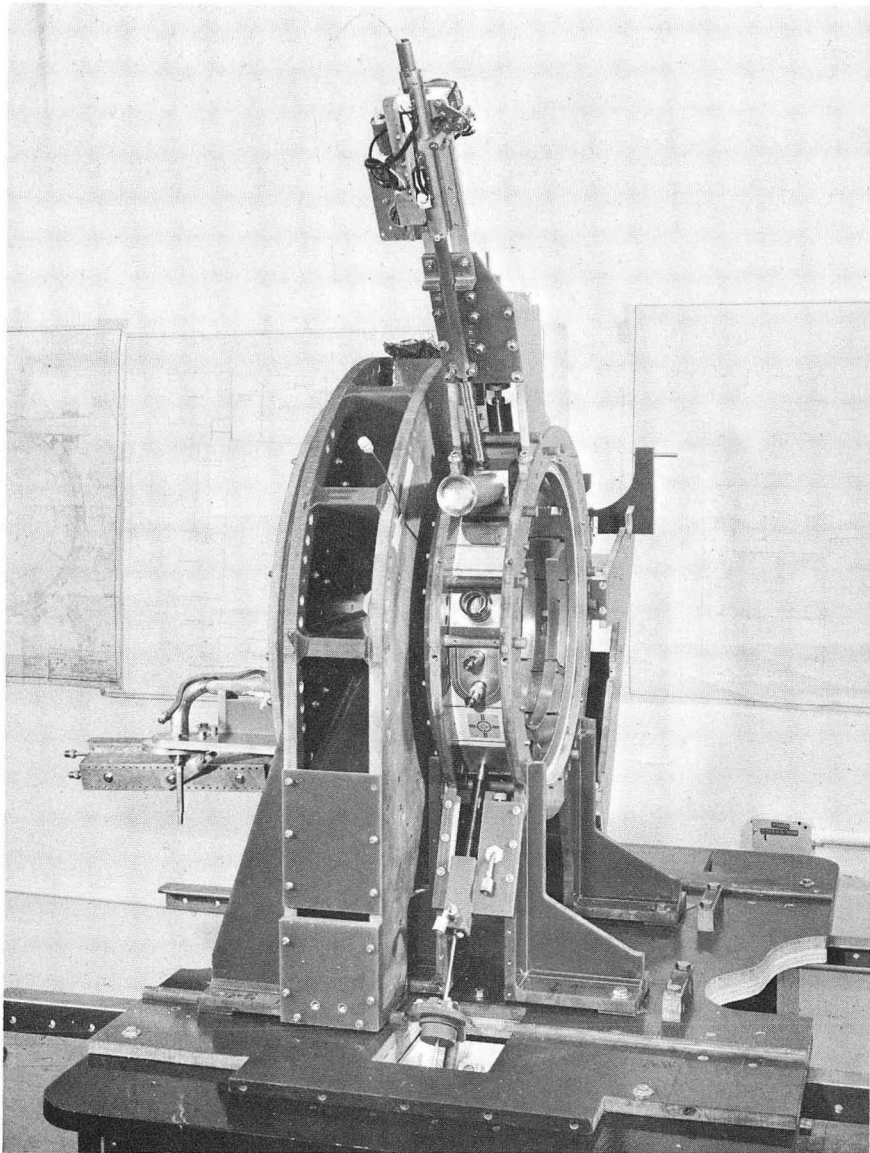
FIGURE CAPTIONS

- Fig. 1. Compressor I with face plate removed. One (outer) coil may be seen, as well as the beam injector pipe (lower left) and the inflector system.
- Fig. 2. Compressor II with one face plate and one side of coil support in place. Beam injection is at the upper front.
- Fig. 3. Overview of Compressor II as assembled in the Astron experimental area.
- Fig. 4. Simplified schematic circuit diagram for Compressor III with ring ejection and magnetic expansion capability (Fig. 4a); and associated current wave forms (Fig. 4b). The current plateaus (whose duration is adjustable) are not truly flat, but have exponential decay with relatively long time constants.



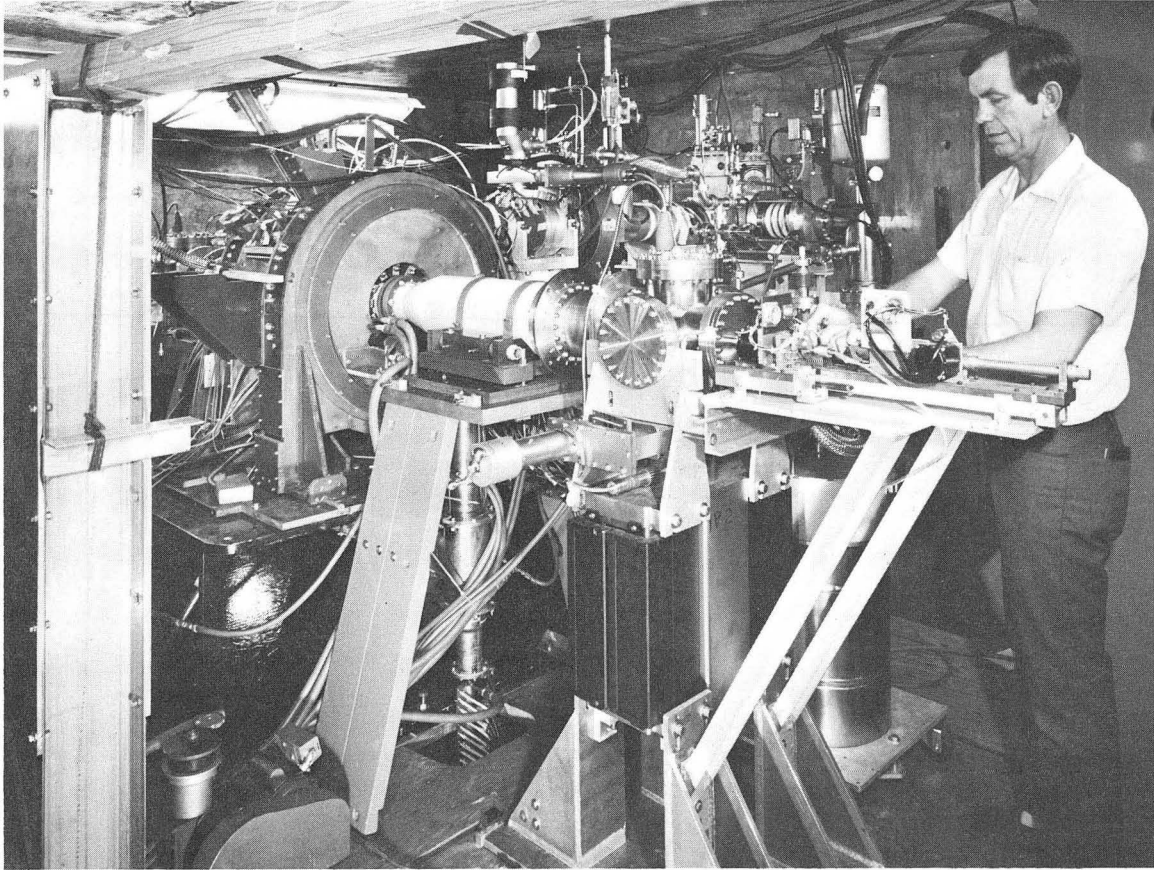
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Fig. 1



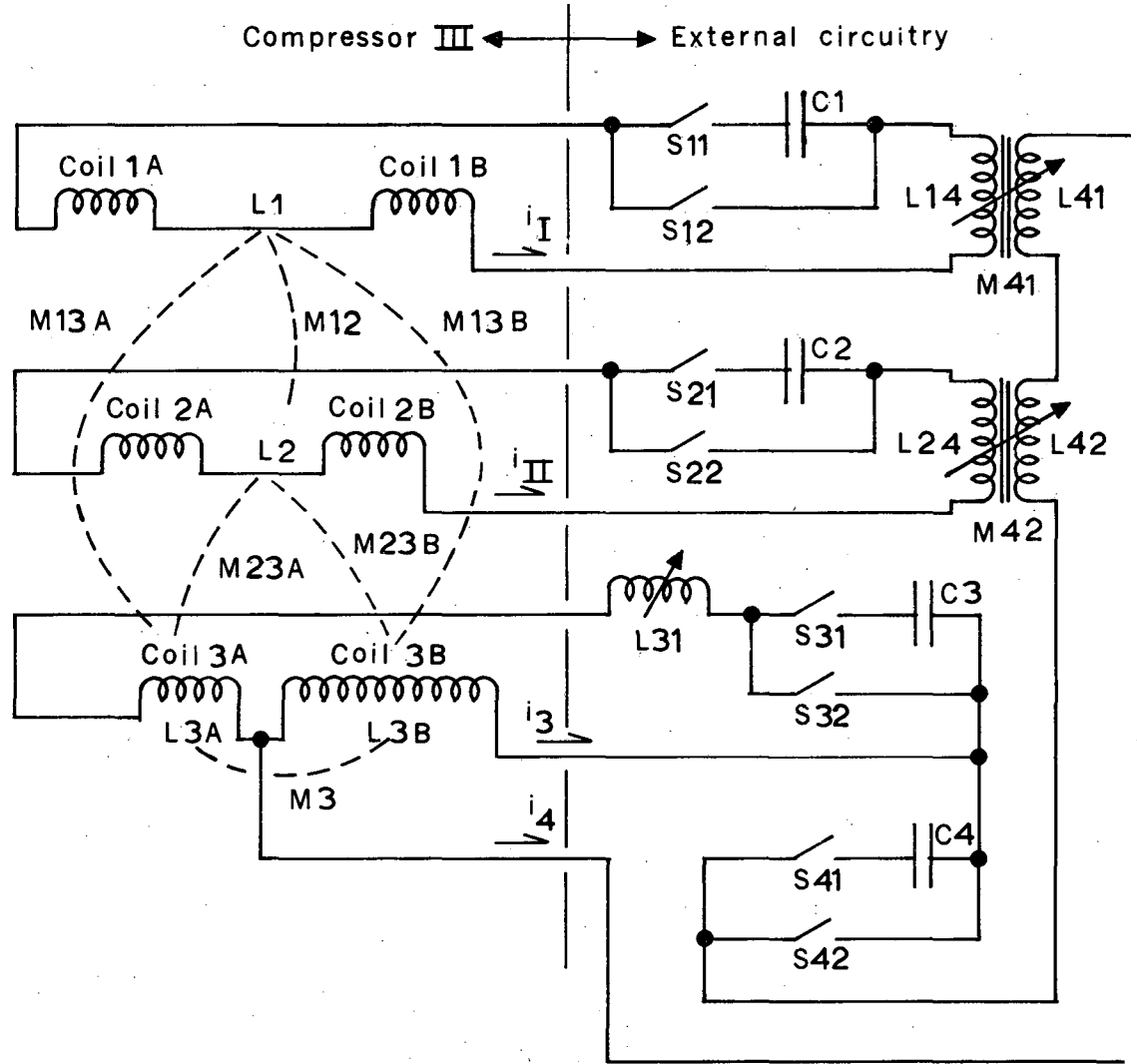
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Fig. 2



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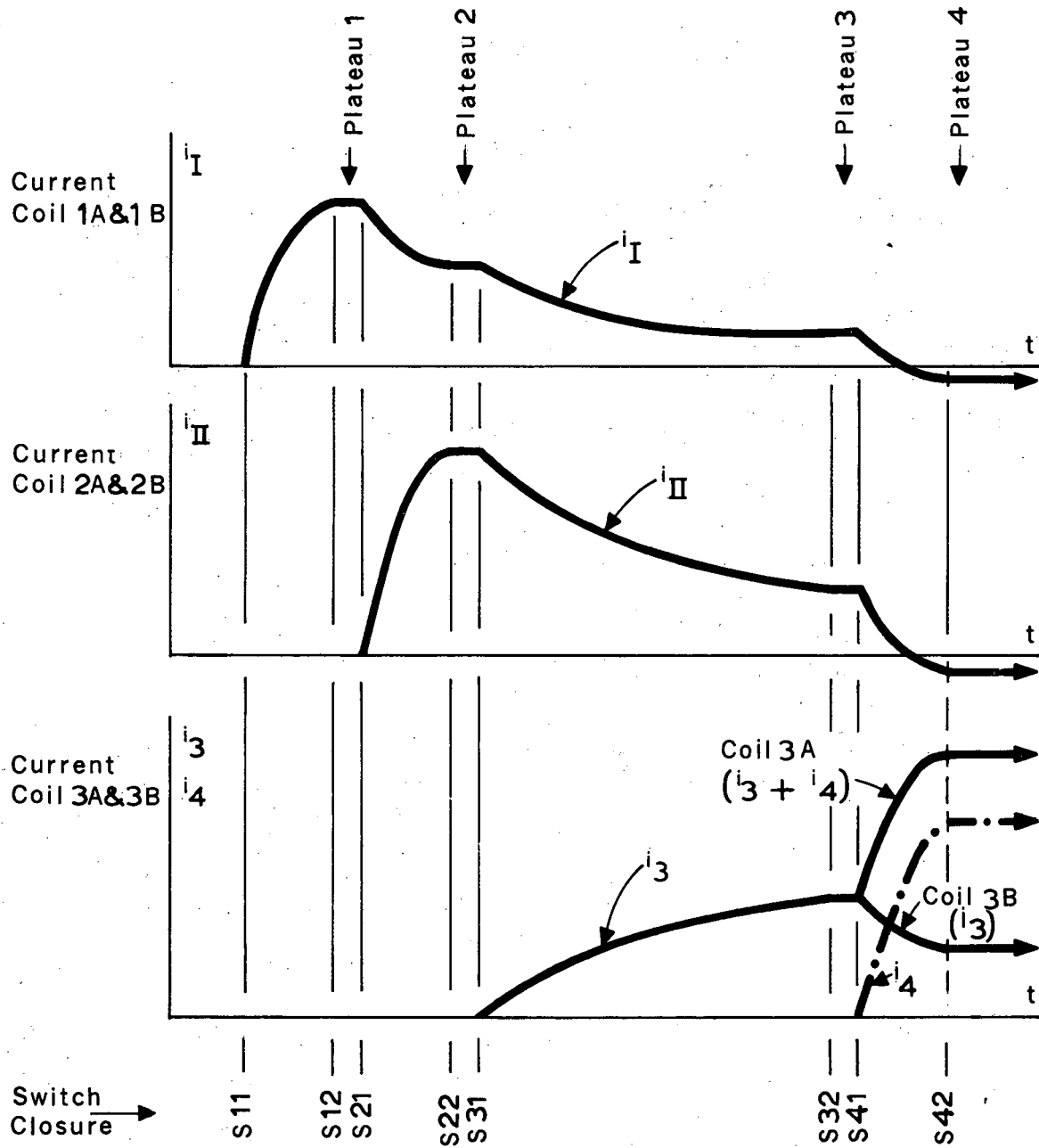
Fig. 3



Compressor III - Simplified Schematic

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Fig. 4a



Compressor III - Waveforms

XBL 689 4927

Fig. 4b

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