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Final Report, Part II
on

Contract No. AT(11-1)-158

H. J. Hausman

June 2, 1954

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AECU-2907

Report No. Final, Part II

RF Project 454

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FINAL

R E P O R T

by

THE OHIO STATE UNIVERSITY
RESEARCH FOUNDATION

Columbus 10, Ohio

To U.S. ATOMIC ENERGY COMMISSION
Contract No. AT(11-1)-158

On DEVELOPMENT OF THE MODIFIED
OHIO STATE UNIVERSITY CYCLOTRON

Submitted by H. J. Hausman

Date June 2, 1954

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DEVELOPMENT OF THE MODIFIED OHIO STATE UNIVERSITY CYCLOTRON

I. INTRODUCTION

This is Part II of a two-part final report to the Atomic Energy Commission concerning the progress of research and development of The Ohio State University cyclotron. Part I of the final report, consisting of a description of the modifications of this cyclotron, was submitted May 28, 1953. Part II of the final report is concerned with the progress of development and the operating characteristics of the modified cyclotron.

II. VACUUM SYSTEM

Each component of the modified cyclotron system was individually vacuum tested prior to assembly. Initial vacuum testing was performed on the completed cyclotron vacuum pumping unit (See Final Report, Part I, page 3)¹ consisting of one Distillation Products MCF-1400 four-stage fractionating oil diffusion pump backed with a Cenco 100 Hypervac mechanical vacuum pump, the pump-box connector from diffusion pump to vacuum tank, by-pass pumping system, and main three inch pumping lines and valves. This pumping system was constructed as a separate unit and mounted on a movable steel carriage having adjustable swivel casters. A General Electric Helium Leak Detector was attached to the by-pass pumping unit through a vacuum valve and served as the detector for leak testing of the system. After the self-contained pumping unit was determined to be leak tight, the unit served as a vacuum pump and detector for locating leaks in the other cyclotron components.

After each component was essentially leak tight, the completely assembled cyclotron vacuum system was carefully leak tested. An ultimate vacuum of $5-7 \times 10^{-6}$ mm Hg has been obtained. This pressure was measured using an electronically regulated RCA 1949 type ionization gauge. As this pressure was deemed practical for cyclotron operation, leak testing was discontinued.

During leak testing of the aluminum cyclotron vacuum tank a series of severe leaks was discovered in the weld joints at three

corners of the tank. Since the outside surfaces of the tank had already been machined to form vacuum surfaces, it was decided to solder the holes rather than risk warping the tank by welding. The holes in the weld joints were enlarged slightly for ease in soldering and the solder, Alsod Aluminum solder, was puddled into the holes while a wire brush was used to scrape the inside surface of the hole.

III. CHARACTERISTICS OF THE ION SOURCE

The ion source is essentially a low voltage gaseous discharge confined within a small Elkonite metal cavity at the center of the cyclotron tank. The discharge is maintained by electron emission from a heated "U" shaped tungsten filament. The ion source is inserted into the vacuum tank at the flange plate between the dee manifolds and extends along the diametral line between dees. A vacuum lock is provided on the ion source housing to allow changing filaments without loss of vacuum in the cyclotron system.

Positioning of the filament with respect to the vertical opening in the discharge cone is critical. Adjustment of this relative position may be accomplished from outside the vacuum system by sliding the filament assembly inside the ion source housing and the accelerated beam monitored at the target position. In order to eliminate other variables, such as electric and magnetic focussing of the resonant beam, which might affect beam intensity, the water-cooled target was placed at a distance of eight inches from the ion source. At each filament position, for a fixed magnetic field and dee voltage, the beam current was maximized by adjusting filament current and arc voltage.

Variations of beam intensity as a function of gas input have not as yet been determined fully. Modifications of the gas input assembly are still under consideration. The length of the existing gas lines which were adapted without major modification from the previous system causes a sufficient time lag in the variations of gas input rate to prevent obtaining valid data on this at the present time.

Positioning of the ion source proper with respect to the geometrical median plane of the tank may be accomplished externally to the cyclotron vacuum tank through an adjustable flexible Sylphon bellows. Variations in the position of the ion source will be made in conjunction with the mapping of the magnetic field and magnetic field shimming.

A satisfactory arc has been observed using 160 amperes filament heater current and with an arc voltage of from 60 to 100 volts.

IV. CHARACTERISTICS OF THE RADIO-FREQUENCY SYSTEM²

The oscillator currently in use was not modified under the AEC contract although modifications are planned for the near future. The oscillator is a self-excited tuned-grid tuned-plate type using two 859 power amplifier triodes operated in push-pull. The tuned-grid circuit consists of two 3 inch copper pipes 24 inches apart each of length equal to one-fourth the resonant cyclotron wavelength. The tuned-plate circuit consists of two water-cooled tank coils connected in series between the plates of the oscillator tubes. In parallel with the tank coils is the variable tuning condenser. The transmission line pickup coil is mounted between the tank coils on a pivot so that its coupling with the tank coils may be varied.

The radio-frequency power is transmitted by the pick up coil through variable coupling condensers into the transmission lines leading to the dee lines. The transmission lines are coaxial dielectric lines of length slightly greater than one-quarter wavelength. The transmission lines are terminated at a suitable impedance level along the inner cyclotron coaxial line, or dee line.

The procedure initially used to tune the cyclotron and oscillator to resonance is the following. Each dee is separately tuned to the same frequency (i.e., resonant³ frequency of one dee and dee line, the other dee being short-circuited to ground) with the tuner and deflector. Frequencies corresponding to the push-pull and push-push modes of cyclotron oscillation are then measured by means of a loosely coupled oscillator and detector. The tuned-grid line of the oscillator is then mechanically adjusted to change its length to correspond to the cyclotron push-pull resonant frequency. The variable condenser in the tuned-plate circuit is then adjusted under no load conditions for minimum oscillator plate current. With the transmission line coupling loop in place, power is increased and the power transmitted to the cyclotron system is monitored by dee pick-up probes. The variables in tuning for a maximum power transfer from oscillator to cyclotron are: coupling loop position, oscillator plate capacity, length of grid line, and cyclotron tuner and deflector.

V. MEASUREMENT OF RADIO-FREQUENCY DEE VOLTAGE

The measurement of the rf dee to ground voltage consists in rectifying the rf voltage picked up across the capacity coupling a sensing probe to the dee proper. The sensing probe or pick-up probe is a length of 1/8 inch solid brass rod placed near the dee and passing out of the vacuum tank through an insulated vacuum seal. The pick-up probe is then connected to a one micro-henry rf choke and IN34A crystal diode, filter, and microammeter. The rectified dc current is then proportional to the peak rf dee voltage. The voltage on each dee is monitored independently.

Absolute calibration of the dee voltage has not yet been completed. Two methods are to be used for calibration over the voltage spectrum. At low rf dee voltages, measurements will be taken by determining the rf current from the deflector electrode to ground. Using a method reported by Danforth and Sampson, one can ascertain the rf dee voltage⁴ by measuring various capacitive coupling parameters of the dee system. At high dee voltages, one can measure such voltages⁵ by detecting the x-rays emitted by electrons impinging on the copper surfaces of the vacuum tank.

VI. MEASUREMENT OF BEAM CURRENT

The circulating accelerated cyclotron beam of charged particles is detected and measured in three ways. On first starting the cyclotron a Geiger counter and counting-rate-meter is used for detecting the beam. Adjusting the various cyclotron components to proper operating conditions is done in conjunction with beam current magnitude, as determined by counting-rate meter reading, at low input power.

The internal circulating beam is detected at the water-cooled target inserted diametrically between the dees. The target is electrically insulated from the grounded cyclotron tank through Garlock Klotz seals whose primary function is a vacuum seal around the movable target shaft. Consequently, the positive ion beam current can be detected directly and read on a microammeter. The large secondary emission current at the target makes these readings somewhat inaccurate. However, these readings serve as a relative beam indication in the region of beam magnitude where the counting rate meter saturates. This type of detection is most useful due to the fact that the time lag in detection depends only on the time

constant of the detecting microammeter. Consequently, any changes in cyclotron operating conditions, which are in general reflected in beam magnitude, can be observed instantaneously and corrected by proper adjustment.

The third method used for detection of the circulating internal beam is measurement of the temperature rise of the target cooling water. The difference in temperature between the input water to the target and the output water is measured by means of a copper-constantin thermocouple whose output voltage is recorded continuously by a Minneapolis-Honeywell "Elektronik" strip-chart recorder. A 500 watt immersion heater is placed in the water line between the target and the "hot" junction of the thermocouple. This heater can thus be used to calibrate absolutely the scale of the strip-chart recorder. The time-constant of the recorder, 2 seconds full scale, is sufficiently fast to permit using the recorder reading as a tuning indication for intense beam currents. It may also serve as a permanent record of bombardment conditions as well as indicating information for yield determinations. Actual bombardment sensitivity of the instrument depends upon beam intensity and target water flow requirements.

VII. PROGRESS

As of January 1954, the physical modifications to the O.S.U. Cyclotron contracted for under AEC contract No. AT(11-1)158 were complete and installed. After the basic electrical wiring was completed, extensive testing of the electrical characteristics of the rf system--including dees, dee lines, transmission lines and terminations, oscillator coupling loop, and oscillator proper--was conducted. To some extent this work is still in progress. Instability of the oscillator and transmission line network has resulted in delays in cyclotron operation. The lower field excitation coils of the cyclotron electromagnet were also removed and cleaned during this period. During the testing of the rf system, interlocks and controls were designed and installed.

On April 29, 1954, a beam of deuterons was detected at a reduced target radius of 8" and at moderate power input. Subsequently the resonant cyclotron beam has been conducted out to a radius of 12". Tests are in progress for determining the nature of the resonant beam as the target radius is increased. Such characteristics as beam intensity, vertical spread of beam efficiency of extraction of ions from ion source, radial oscillations of the beam, and magnetic and electric focussing, are being investigated as a function of beam radius.

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Investigator _____ Date _____

Supervisor H. J. Hausman Date 6/8/54

FOR THE OHIO STATE UNIVERSITY RESEARCH FOUNDATION

Executive Director Oram C. Woolpert Date 6/8/54
RTH

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PHOTO NO. 1. Assembly View of Dees, Coaxial Quarter--
Wavelength Resonant Dee Lines, and Carriage.

PHOTO NO. 2. Assembly View of the Modified Components
to the O.S.U. Cyclotron: Vacuum Tank,
Pumping Unit, and Resonant Lines.

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All external bolt holes $\frac{5}{16}$ -18 x $\frac{5}{8}$ Stainless steel Helicoid inserts
 Liner mounted before welding. Joint $\frac{5}{32}$ x $\frac{3}{16}$ Brass F.H. Box $\frac{10}{32}$ x $\frac{1}{4}$ Brass F.H.
 Remove liners for welding.

CYCLOTRON

TANK ASSEMBLY

7743 C9

TK-1

5

14

$\frac{1}{4}$ " Alum tank wall

Silver solder - vacuum joint

Silver solder - vac. joint
Round to enter O-ring

Silver solder - bore to enter tube

Copper tube - split every 45°

Soft solder - vac. joint

Silver solder
Silver solder - round edges

$\frac{3}{16}$ " OD. Copper tubing

Bore $\frac{1}{2}$ " D. x $\frac{1}{4}$ " long.

$\frac{3}{4}$ " OD. Stainless steel 5" Thread $\frac{3}{4}$ -16 x 4"

$\frac{5}{8}$ " OD. x $\frac{1}{16}$ " Brass

$\frac{1}{4}$ "

Polish outside for O-ring

1" OD x $\frac{1}{16}$ " Copper 4 Smooth outside

TOP VIEW Section AA

Copper cover

Silver solder all around - round edges
Typical section BB

CYCLOTRON
TUNER ASSEMBLY

CA-1

CYCLOTRON
ION SOURCE ASSEMBLY

Section A-A

 $\frac{1}{2}$ " R. Round all edges. $\frac{8}{32}$ Brass screws. Countersink flush. $\frac{1}{8}$ " Brass connector $10\frac{1}{2}$ $\frac{8}{32}$ Brass screws. Chtrsk. Flush. $\frac{1}{2}$ of Dee Line

24ST Alum. frame

Approximate shape of $\frac{1}{4} \times \frac{1}{2}$ waveguide cooling.
Soft solder to inside of 24 oz. soft copper cover.

 $\frac{1}{2}$ of Tank $24\frac{3}{4}$ Tank wall

Center of Dee System

Section B-E

CYCLOTRON
DEFLECTOR DEE

DE-1

CYCLOTRON

VACUUM PUMP SYSTEM

56

57

58

59

14

Dea hanger only

SECTION AA

72

73

74

75

75

24 $\frac{3}{4}$ "
to center of Dees

Dee vertical adjust
Screw 10 t.p.i.
Bodine $\frac{1}{2}$ H.P. motor Type NSI-34
Geared 1600:1

Silver solder - vac. joint

Silver solder - vacuum joint

Silver solder - vac. joint

Dee line support

6" H-beam

Dee horizontal adj. screw

Removable pivot

Alum. saddle

14 $\frac{1}{2}$ " OD $\times \frac{1}{8}$ " Cu tubing

Alum. clamp

C of Carriage

C of Dee system

Ion source port

Alum. cross plate
O-ring both sidesOne swivel caster - adj.
On center lineTwo track wheels - adjustable
Separation 29 $\frac{1}{2}$ "Two track wheels - adj.
Separation 29 $\frac{1}{2}$ "Two swivel casters - adjustable
Separation 41 $\frac{1}{2}$ "

Approx. floor level

CYCLOTRON

DEE MANIFOLD-CARRIAGE

76

77

78

79

7743 17

MN-1