321

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MIDWESTERN UNIVERSITIES
RESEARCH ASSOCIATION

QUARTERLY REPORT

TO THE

ATOMIC ENERGY COMMISSION

FOR THE PERIOD
APRIL 1, 1957 TO JUNE 30, 1957

MADISON, WISCONSIN
JULY 1, 1957

QUARTERLY REPORT
TO THE
ATOMIC ENERGY COMMISSION

INTRODUCTION

REPORT OF THE EXPERIMENTAL DIVISION

REPORT OF THE THEORETICAL DIVISION

REPORT OF THE COMPUTER DIVISION

PUBLICATIONS AND ABSTRACTS

Introduction to MURA Quarterly Report to the AEC
For the Period April 1 to June 30, 1957

It is evident from the subsequent detailed sections of this report, that the work of the MURA Laboratory in the Experimental, Theoretical & Computer Divisions has progressed excellently during the quarter now ending as is evidenced by 8 MURA reports, one published paper, and 23 new or revised programs for the IBM 704 computer.

However, the financial support and interest of the Commission in the MURA program as expressed in the budgetary limitations for Fy 58 (a reduction of 25% from Fy 57 and 50% in the amount requested in Fy 58) and the lack of expressed interest for continuing support in future years has been the cause of great discouragement and concern among MURA Laboratory Staff Members. This is particularly evidenced by the delay in the construction of the high-current FFAG Model (approx. 75 mev electrons with an anticipated circulating current in the region of 100 to several thousand amperes). It has prevented this phase of the MURA program from proceding in an orderly and efficient way. In fact, this restrictive action on the part of the Commission could be responsible for the collapse of the entire MURA effort and organization. This situation has been discussed, with the Research Contract Director of the AEC Chicago Operations Office who is fully aware of the implications. It is believed that he has been sympathetic to our needs and problems.

REPORT OF THE EXPERIMENTAL DIVISION

During the period April 1 through June 30, the main experimental effort has been on magnetic field measurement techniques, rf tests with the radial sector model, and assembly of the spiral sector model parts.

A UCRL magnetometer was constructed for us by Professor Joseph Ballam's group at Michigan State University. This is the magnetometer that was used in the field tests of the Thomas cyclotron at the Berkeley Radiation Laboratory several years ago and it should be very helpful to us in measuring our fields in the region of 30 and 100 gausses. There are problems with the zero drift of this instrument which must be solved. Flip-coil methods have to be pushed hard in the measurements of k and the magnetic field. It is hoped that the magnetometer will assist this work.

All coils for the spiral sector machine were reformed to be almost exactly the same shape to avoid field bumps in the spiral sector accelerator and subsequent field tests have shown that this and the re-machining of the poles were important. The median plane magnetometer was put into operation and means of adjusting the median plane of the magnet to the geometrical median plane were found. A simple operation of adding reluctance turns on one pole and subtracting them from the other pole of the same magnet corrects this plane without altering k. The magnets and coils are now being permanently wired together.

Some tests were made on the scanning of betatron phase space during injection into the radial sector model. The method used could be called radio frequency "knock in" in contrast to "knock out". As is well known radio frequency "knock out" occurs if a radio frequency field capable of exciting

betatron oscillation is applied to the beam. However, such a radio frequency field, if in the right phase, will damp betatron oscillations. This might be termed radio frequency "knock in"; but the radio frequency field must be either turned off or the orbit must escape the region of field before the radio frequency field "knocks out" the particles which were "knocked in". This type of radio frequency effect has been shown to work in experiments with the radial sector accelerator and this should be encouraging to the Oak Ridge National Laboratory Accelerator Group, who propose this method for scanning betatron phase space by cyclotron injection. The main difference between the Oak Ridge proposal and our tests, is that the radio frequency "knock in" field in the Oak Ridge case can be carefully phased with the injected bursts of particles so that all particles are "knocked in" and none are "knocked out". In tests with FFAG radial sector acceleration continuous injection was used and consequently more particles were "knocked out" than were "knocked in". There is a numerical connection between parameters necessary for scanning the betatron phase space by this radio frequency damping process and by the method of kinking the closed orbit which was described in the MURA proposal to the A.E.C. for a combination of 15 bev accelerators.

If the rf voltage provides successive small impulses to particle bunches at exactly the right phase, the kva necessary to scan phase space is the same for each method. But the case in which the equilibrium orbit is kinked and straightened out at a relatively low rate of change generally requires several times less kva than the rf method. These systems of multi-turn injection studied by Oak Ridge and by MURA appear to have a great deal of merit. The

kink system has been used in accelerators - mainly in the Berkeley electron synchrotron. These methods may be considerably simpler than the use of the regenerative peeler as an injector.

Studies of thick formed coils for the high intensity electron model mentioned in the last report have been continuing. The use of eigenpoles appears to be more difficult than we imagined when applied to small k models. In case of slotted poles in which the thick coil is placed, such as it is in armatures, has attractive features. The high intensity electron model parameters which have been adopted are k approximately 9.3, N = 16 sectors, injection around 150 centimeters at 100 kilovolts and the final radius of 244 centimeters between 30 and 50 mev if the beam is run in only one direction and about 33 mev if the beam is run in both directions.

The auxiliary circuits for the spiral sector model are almost complete. Inflector-injector structures have been under test in a vacuum system. This inflecting system should provide much more injected current with small amplitude betatron oscillations.

REPORT OF THE THEORETICAL DIVISION

Continuing progress is being made in non-linear orbit theory. Theoretical formulas for stability limit amplitudes in the neighborhood of various resonances are being worked out and tabulated. These formulas are then checked against digital computations. Computational and theoretical studies on the effects of misalignments on stability limits are in progress. Relations between simple algebraic transformations and differential equations have been worked out, so that it is now possible to utilize the extremely rapid computations of algebraic transformations in studying the behavior of accelerator orbits.

Extensive computations concerning rf acceleration processes are partially completed. A major part of the computations concerns a process of stacking intent beams of particles. Computations are also under way which will study the process of picking up and depositing particles from rf buckets which will study the acceleration of particles through the transition energy and computations have been considerably speeded up by a number of modifications in the computer program and particularly by an adaptation of the computer program to oscilloscope output and recording.

A major part of the computation effort is now being devoted to the selection of structures and parameters for the next electron model which is to be built. These computations have already limited the choice of structures and parameters down to a point where it will very shortly be possible to begin the design of the magnets and the ordering of the necessary materials.

Theoretical studies are in progress concerning space charge and plasma effects which will arise when intense beams of electrons are established in the next electron model. Detuning effects of space charge both on betatron and synchrotron oscillations have been worked out. Relationships between energy, vacuum and time required for the build up of a compensated plasma have been computed. Instabilities consequent upon the build up of this plasma are under study.

PROGRESS REPORT

Computer Division

April 1 - June 30, 1957

During this period the use of the MURA IBM 704 Electronic Data Processing Machine was gradually increased from one shift per day to two shifts per day (16 Hours). The utilization rate for April was approximately 84% of the total time spent in valid computation. During the months of May and June this rate was maintained at 74% even in the face of an increasing (and for us unusual) amount of machine and air conditioning breakdown.

This period was especially marked by the arrival and installation of a cathode ray output recorder. This piece of equipment enables results from the computer to be displayed both visually and photographically in a much more easily understood fashion and in a time much shorter than other output modes. This instrument has hence greatly increased the usefulness and effectiveness of the computing machine.

During this period 23 new programs were either put into effect or commenced. These fall into several groups.

A rather complete set of library routines to utilize the oscilloscope output in various ways and under various conditions was prepared.

A second group of programs consisted of complete modifications of all the important accelerator production programs so as to utilize the scope output.

An extensive investigation of the effect of round-off error and propagated error in iterative algebraic transformation programs was undertaken and is still continuing. A very preliminary generalization points to the conclusion that floating point arithmetic is subject to too small a precision and too great a round-off bias to permit the exceedingly long runs which are necessary to decide the very important questions pertaining to long-term stability of particle orbits in accelerators.

Preliminary work was begun on a set of library programs in the area of linear algebra with especial reference to matrix diagonalization programs.

Work was begun and is continuing on an interpretative system to simulate the IBM 650 Computer on the IBM 704 Computer. This would enable the large body of existent programs prepared for the smaller and less powerful 650 to be run on the 704.

Preliminary study and programming was begun on two large programs which will continue throughout the present contract year. These are a study of the face-centered cubic binary alloy and a study of the numerical wave functions of the hydrogen-like molecule.

MIDWESTERN UNIVERSITIES RESEARCH ASSOCIATION

COMPUTER DIVISION

PROGRAM INDEX

Program Sequence Number	Name	SHARE Mnemonic	MURASS Identification	Production Number	Status	Author
104	Floating Decimal Dump	MU FDD2	LN208			McNall
105	Variable Column Fraction Cathode Ray Tube Display	MU SCP5	LJ610			King
106	Six Column Integer Cathode Ray Tube Display	MU SCP6	LJ611			King
107	Variable Column Integer Cathode Ray Tube Display	MU SCP7	LJ612			King
108	Fixed Point Square Root	MU SQR3	LB417			Fosdick & Snyder
109	Fixed Point Cube Root	MU CRT2	LB418			Snyder
110	SAW TOOTHED POLLY			P110		Clark
111	Floating Multiply and Round or Floating Add and Round	MU MAR1	LA126			Storm
112	MONTE CRYSTO I			P112		Fosdick
113	SCOPE FORMESH (INVARIANT)			P113		Snyder
114	SCOPE FORMESH (INVARIANT) FUMBLEBUMPS			P114		Snyder
115	SCOPE FORMESH (INVARIANT) GRUMBLEBUMPS			P115		Snyder
116	SCOPE INVARIANT DUCK BUMPS			P116		Snyder
117	LINEAR ALGYTEE			P117		Hutchinson
118	EQUICYL SCOPE			P118		Snyder
119	TTT SCOPE			P119		Snyder
120	CHANNEL 5			P120		Fosdick
121	ALGYTEE SCOPE			P121		Storm
122	CROCOR			P122		McNall
123	HYDMOLYGN			P123		Fosdick & Snyder
124	Diagonalization of a Symmetric Matrix -- Jacobi Method	MUMAD1	LF204			Kister
125	Random Number Generator	MU RAN2	LG503			Chapman
126	Random Number Generator	MU RAN3	LG504			Chapman

PUBLICATIONS AND TECHNICAL REPORTS ISSUED SINCE

MARCH 31, 1957 AND THEIR ABSTRACTS

THE 2 $\nu_y - \nu_x = 0$ DIFFERENCE RESONANCE. G. Parzen. April 1, 1957, MURA #250

Some results for the $2\nu_y - \nu_x = 0$ coupling resonance are presented in a rough form. No derivations are given. Threshold value of μ and γ for growth are given. Results are also given for the turnover point when growth occurs and for the true stability limits.

A RADIO FREQUENCY SYSTEM FOR EXPERIMENTS WITH THE FFAG ELECTRON MODEL. K.M. Terwilliger. April, 1957. MURA #254

A frequency modulated oscillator using ferroelectric capacitors has been constructed for rf experiments with the FFAG electron model. The system gives about 50 peak rf volts and a frequency swing from 65 to 75 Mc on the 150 $\mu\mu f$ vacuum tank gap. Closely spaced frequency modulated rf pulses, up to four or five per millisecond, are available for rf beam stacking and other experiments.

RADIO FREQUENCY EXPERIMENTS WITH AN FFAG ELECTRON MODEL ACCELERATOR. K. M. Terwilliger, L. W. Jones, & C. H. Pruett. April, 1957. MURA #255

Radio frequency experiments performed on the FFAG electron model accelerator demonstrate predictions of the Symon-Sessler rf acceleration theory. In particular the experiments show the phenomena of phase displacement in which a frequency modulated rf pulse, with frequency starting below that of a coasting beam, and sweeping through it, captures only a few particles and decreases the energy of the remainder a predictable amount. Measurements of the amount of average and peak energy loss of the coasting beam are in rough quantitative agreement with the theoretical predictions. Some qualitative tests are made which demonstrate beam stacking.

EXPERIMENTS ON RADIO FREQUENCY KNOCKOUT OF STACKED BEAMS. L. W. Jones, C. H. Pruett & K. M. Terwilliger. May, 1957. MURA #260

A major problem in the building up of intense circulating currents in a FFAG accelerator is the effect on the stacked beam of the radio frequency voltage accelerating additional particles. When this accelerating frequency is in resonance with the betatron oscillations of the stacked beam, the oscillation amplitude may be driven and the beam destroyed. Experiments have been performed with the radial sector FFAG electron model which demonstrate that the quantitative magnitude of the effect is in agreement with calculations.

A SPECULATION ON A METHOD OF PROPULSION BY ION THRUST. Tihiro Ohkawa. May, 1957. MURA #261

An amateurish method of obtaining ion thrust by using the drift of a plasma in a magnetic field similar to the adiabatic expansion of gases is discussed. The method is also applicable to ion vacuum pumps. An interesting feature of the engine is that it can be driven directly by thermonuclear reactor.

COMPUTATIONAL EXAMPLES OF SOLUTIONS TO DIFFERENTIAL EQUATIONS WHICH SIMULATE GROWTH OF AXIAL OSCILLATIONS IN A FFAG ACCELERATOR OPERATED NEAR THE $\sigma_x = 2\sigma_y$ RESONANCE. L. Jackson Laslett. June 7, 1957, MURA #295

The effect of various coupling terms upon the ψ-growth phenomenon for an operating point near the $\sigma_\rho = 2\sigma_\psi$ resonance is examined computationally. Results are presented in tabular form and graphically. A tentative discussion of the results is also given.

ELECTRONIC DEVICES USING PLASMAS IN A MAGNETIC FIELD. Tihiro Ohkawa. June 14, 1957. MURA #310

Electronic devices, such as linear accelerators, traveling wave tubes, klystrons and magnetrons, using the hydromagnetic wave in a plasma are discussed. Though they might not be too practical, they have interesting possibilities, for example, a linear accelerator driven by a d.c. power and a method of obtaining a high temperature. There also are discussed slow devices i.e. diodes, triodes and junctions.

PROPERTIES OF NEUTRALIZED RELATIVISTIC ELECTRON BEAMS. J. Enoch. June, 1957. MURA #311

The equilibrium properties of an intense, radiation-pinched, electron beam, which is neutralized by positive ions in the laboratory system, are studied. The motion of a test electron in such a beam is treated statistically, taking into account radiation damping and collisions with positive ions. By requiring that the calculated distribution of electrons as a function of distance from the center of the beam be equal to the distribution assumed in writing down the equations of motion, an expression for the equilibrium current is obtained. An expression for the equilibrium minor radius of the beam in terms of the acceleration

per turn available is also obtained. An apparent discrepancy between the value of the equilibrium current as obtained in the present report and the value given by Budker is explained in terms of assumptions about the energy distribution of the electrons.

AN ELECTRON MODEL FIXED FIELD ALTERNATING GRADIENT ACCELERATOR. F. T. Cole, R. O. Haxby, L. W. Jones, C. H. Pruett & K. M. Terwilliger. March 5, 1957. Published by Review of Scientific Instruments, June, 1957. MURA #219

A radial sector FFAG accelerator has been constructed and successfully operated. In this 8 sector accelerator electrons are betatron accelerated from 25 to 400 Kev using both continuous and pulsed injection. The number of radial betatron oscillations per revolution may be varied from 2.3 to 3 and the number of vertical oscillations per revolution from 1 to 3. Calculations of these oscillation frequencies using various approximations are described and discussed. These frequencies have been measured statically with the unaccelerated beam and dynamically using an rf perturbing voltage on the accelerated beam. Results of these calculations and experiments are in satisfactory agreement. Effects of misalignments have been measured and are in close agreement with calculations presented. A survey has been made over a large area of the betatron oscillation stability region. The effects of the many resonances observed are in good qualitative agreement with theory.