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FINAL REPORT OF WORK IN SUPPORT OF THE NRL FEL PROGRAM.(U)

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FINAL REPORT OF WORK IN SUPPORT OF THE NRL FEL PROGRAM

during the period 14 March, 1982 to 15 September, 1982

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INTRODUCTION

>The Naval Research Lab. (NRL) Free Electron Laser (FEL) program proposed to use the NRL electron linear accelerator (LINAC) as a source of electrons for its studies. The FEL experiment will place very exacting demands on the parameters of the electron beam from the LINAC. Therefore a careful study of the present operation of the LINAC was necessary in order to determine exactly where and how modifications and improvements could be made to best meet the needs of the FEL program. To do this the system was considered in the following segments;

1) Electron injection electronics,
   a) Master timing circuits,
   b) Electron gun modulator,

2) Electron beam injection hardware,
   a) Emittance definition,
   b) Focusing,
   c) Bunching,

3) Accelerating structure,
   a) Acceptance,
   b) Focusing,

4) First 90 degree bend and energy definition,
   a) Beam spot characteristics,

5) Transport from room 105a to room 103a,
   a) Beam alignment,
   b) Magnetic fields in the wall,

6) Second 90 degree deflection,
   a) Beam alignment,
   b) Beam spot characteristics,

7) Beam dump system,
   a) Radiation safety,
   b) Use as a spectrometer.

LINAC MASTER TIMER

In reviewing the many requirements that the FEL experiment would place on the LINAC it was determined that the existing master timer was not satisfactory. The FEL experiment will require the fastest possible risetime on the electron pulse and its uncertainty (jitter) must be as small as current techniques allow.

It was determined that the master timer which was currently in use to provide trigger pulses for the various modulator systems on the LINAC (RF source, klystrons, and the gun) was not performing up to the standards required by the FEL experiment. However, a very fine master timer had been built. It was not in use because its master oscillator was unstable and the timer generated spurious pulses. KM Sciences undertook to debug this system.

The master oscillator consisted of a phase locked loop sensing a 120 hz signal from the AC line. A considerable improvement in stability was achieved by filtering the 120 hz signal and adding some filtering to the feed-back circuit of the phase locked loop. The corrections to the master oscillator are shown in figure 1. Some jitter remained,however, when the preset counter feature of the timer was activated.It was found that the l e d display of the preset counter which was operating from the same power source as the master oscillator was introducing a lot of ripple on the main power buss. A seperate power supply was added to operate the l e d display and this cleared up that jitter problem.

Some modification of the delays of the master timer were also made at request of the LINAC operating crew.

ELECTRON GUN MODULATOR

On checking out the electron gun modulator it was found that a hydrogen thyrotron trigger tube was used with a pulse forming line to generate the electron gun pulse. This system had a risetime of about 50 nanoseconds and a jitter of 25 to 30 nanoseconds. In addition, the light link had a very slow risetime which added to the uncertainty of timing.

KM Sciences found that there was a company which manufactured an electron gun modulating system which was completely compatible with both the needs of the FEL experiment and with the NRL LINAC electron gun. This system would be capable of providing a peak current of 25 Amperes in the short pulse mode, and up to 10 Amperes in the long pulse mode. In the short pulse mode it would provide pulse lengths from 5 to 100 nanoseconds,and in the long pulse mode, pulse lengths from 0.1 to 10 microseconds. Operating in the short pulse mode, the risetime would be about 1 nanosecond, and in the long pulse mode it would be less than 15 nanoseconds. Jitter in either mode was less than 5 nanoseconds. KM Sciences assisted NRL in preparing specifications and in placing an order for the above described system.

ELECTRON INJECTION SYSTEM

The injection system of the NRL LINAC, as it is presently configured, produces a beam at 30 Mev with a radius of about 0.7 cm and a divergance of about a part in a thousand. This corresponds to a normalized emittance of less than pi mm milliradians which would not be too bad for the FEL experiment were it not for the fact that the beam spot is so large. Also this emittance is the result of the limiting acceptance of the LINAC accelerating structure. Hence the machine is operating quite inefficiently. This inefficiency is due to the fact that the present injection system has no limiting apartures in it to define the beam before it enters the accelerating structures. An oversize beam entering the accelerator excites many transverse modes which in turn defocus the beam and considerably reduce the amount of current which can pass through the LINAC.

KM Sciences recommends that suitably designed apartures and additional focusing elements be added to the existing injection system. This will result in limiting the beam to the vacinity of the axis of the accelerator were it will not excite unwanted transverse modes which in turn should allow the acceleration of more current than was previously possible. In addition, it will allow the electron gun to operate in the manner in which it was originally designed to run and also allow the LINAC operators to better adjust the bunching and preaccelerating units. Preliminary estimates by KM Sciences indicates that this can be accomplished within the existing length restrictions.

ACCELERATING STRUCTURES

There is some evidence that the third and perhaps the second sections of accelerating wave guide are defective. Measurements of the voltage-standing-wave ratio gave large values for these sections. KM Sciences assisted in the design and installation of reactive sections to the loads on these two wave guides and the voltage-standing-wave ratio was reduced to an acceptable value. This did not result in any improvement in the performance of the LINAC. It is probable that the effects of the previously described injection problems outweighed the effect of reflected signals. This potential problem can be studied more effectively after the recommended improvements in the injection system are completed.

BEAM TRANSPORT SYSTEM

The overall layout of the LINAC and the beam line associated with the FEL experiment is shown in figure two. The NRL LINAC facility consists of several rooms, one of which houses the accelerator itself and beam distribution plumbing. This arrangement "bottles up" a large part of the background radiation associated with the accelerator thereby providing a relatively clean environment for experiments carried out in the adjoining rooms.

The beam is transported into experimental room 103a (see figure 2,) by a 90 degree achromatic deflection system of the Penner-Brown configuration. It consists of two 45 degree deflection double focusing wedge magnets which are mirror images of each other. These wedge magnets are separated by a distance of twice their focal length, and a quadrupole singlet is placed at their common focus on the mid line of the system. Figure three is a diagram of such a system. the first wedge magnet focuses the beam at the mid line of the system but electrons of a higher or lower energy are focused at lessor or greater deflection on this mid line. The quadrupole singlet is arranged to be focusing in the horizontal plane and gathers these divergent off energy beams back to pass through the second wedge magnet. Thus the system is achromatic for all energies which can get through the quadrupole. A pair of slits placed to close along the mid line of the system serve to define the energy band width which the system will pass. These slits are adjustable from zero to about 6% allowing the operator to select the energy range he wishes to transport to the experimental area.

When the LINAC first became operational this deflection system had been carefully set up and adjusted. It performed as designed with a high degree of precision. However, through the years many small adjustments added up to a significant degradation in the performance of this system. It was found necessary, in setting up the beam line for the FEL experiment, to realine this 90 degree deflection system. Considerable care was taken to return it to the original designed configuration

Once this had been accomplished ,the beam spot was located at two points in room 105a. The first just after the 90 degree deflection system and a second about 5 feet across the room. These spots were about 1.5 centimeters in diameter and their centroids were located to about one millimeter. This then determined a line through the wall separating rooms 105a and 103a. A beam pipe was carefully centered on this line and rigidly mounted to the wall, thereby providing a fixed reference for further alignments. Steering coils are provided along all long runs of beam plumbing to allow one to cancel out the effects of stray magnetic fields. Once this plumbing was evacuated and a beam was put through it, it was found that a larger steering power supply was needed to bring the beam in line in room 103a. This was attributed to stray magnetic fields due to reinforcing iron that had been cut off inside the wall when the hole had been drilled through it.

Once the beam line was established in room 103a a second 90 degree deflection system was set up to direct the beam to the FEL experiment. This deflection system was identical to the first one except that it had no energy defining slits, as none are needed. The second 90 degree deflection system was also carefully set up to conform to its original design. The second deflection system was powered by a new power supply slaved to the power supply for the first deflection system so that it would exactly track it. Additional cooling had to be supplied in room 103a to handle the needs of the second deflection system and to cool both a "dump" system and a spectrometer magnet needed for another experiment.

After setting up the second deflection system the beam spot was again observed at two points after the second system. This again provided two points to establish the beam line through the FEL experiment. A small rectangular aparture placed at this point serves to define the beam shape and position as it enters the FEL experiment. Beam current monitors were placed at several locations along the beam line from the LINAC to the FEL experiment to aid the operators in setting up the LINAC. In addition, A quadrupole doublet is being designed to shape the beam more efficiently for the FEL experiment.

BEAM DUMP SYSTEM

A beam dump magnet was placed at the end of the beam line just after the FEL experiment. This magnet was designed to provide two useful features; first to provide a means of disposing of the beam in a fashion which would not produce a serious radiation problem, and second to provide a means of determining the energy spread of the beam after it traversed the

FEL experiment. The dump magnet showing the electron paths through it is illustrated in figure four. This magnet was designed to have a very large acceptance to allow for scattering by an exit window. It is capable of bringing to focus a beam of monoenergetic particles at a point 30 inches below the beam line. It will accept an energy spread of 10% with a dispersion of about 2.5% per inch at the focal plane. It is therefore capable of serving as an energy spectrometer when provided with a suitable position sensitive electron detector.

RADIATION SAFETY REVIEW

Calculations were made to estimate the radiation hazard constituted be the FEL experiment to the rest of the building. Calculations were made assuming that a 30 Mev beam was incident on a high Z target at the location of the dump magnet. This was construed as the worst case accident, i.e. the beam was turned on but the dump magnet failed to operate. Under this condition with the Linac operation at 20 pulses per second it was found that about 8 inches of lead was required at the north wall of room 103a . This additional shielding will be put in place and a radiation survey will be performed to determine its adequacy.

SUMMARY

In summary, the following is the status of the NRL LINAC as it will function in support of the FEL experiment:

1) The improved master timer for the LINAC has been debugged and should provide the precision needed for the FEL experiment.

2) A new electron gun modulator has been ordered which will be capable of providing all the needs of the LINAC for the FEL experiment and all other anticipated programs.

3) The beam transport system has been carefully alined to deliver the beam to the FEL experiment.

4) Current monitors and apartures have been installed to define the beam as it enters the FEL experiment.

5) A beam dump system has been installed which will provide a safe means of disposing of the beam consistent with the radiation safety standards required by NRL.

6) The beam dump magnet will provide a means of energy analizing the beam when a suitable position sensitive beam detection system is add to it.

KM Sciences recommends that the injection optics of the NRL LINAC be upgraded to inject a beam of considerably smaller crossection in to the linac. This should produce a significant improvement in the operation of the LINAC and ,in addition, provide a beam of much smaller emittance to the FEL experiment.

CONTACT WITH OTHER FEL PROGRAMS

Throughout the year KM Sciences has attended reviews of other FEL programs at the University of California Santa Barbara, and at Stanford University. In addition, KM Sciences has been in contact with key people in the FEL program at Los Alamos. KM Sciences has also kept in contact with accelerator technology at other institutions throughout the United States.

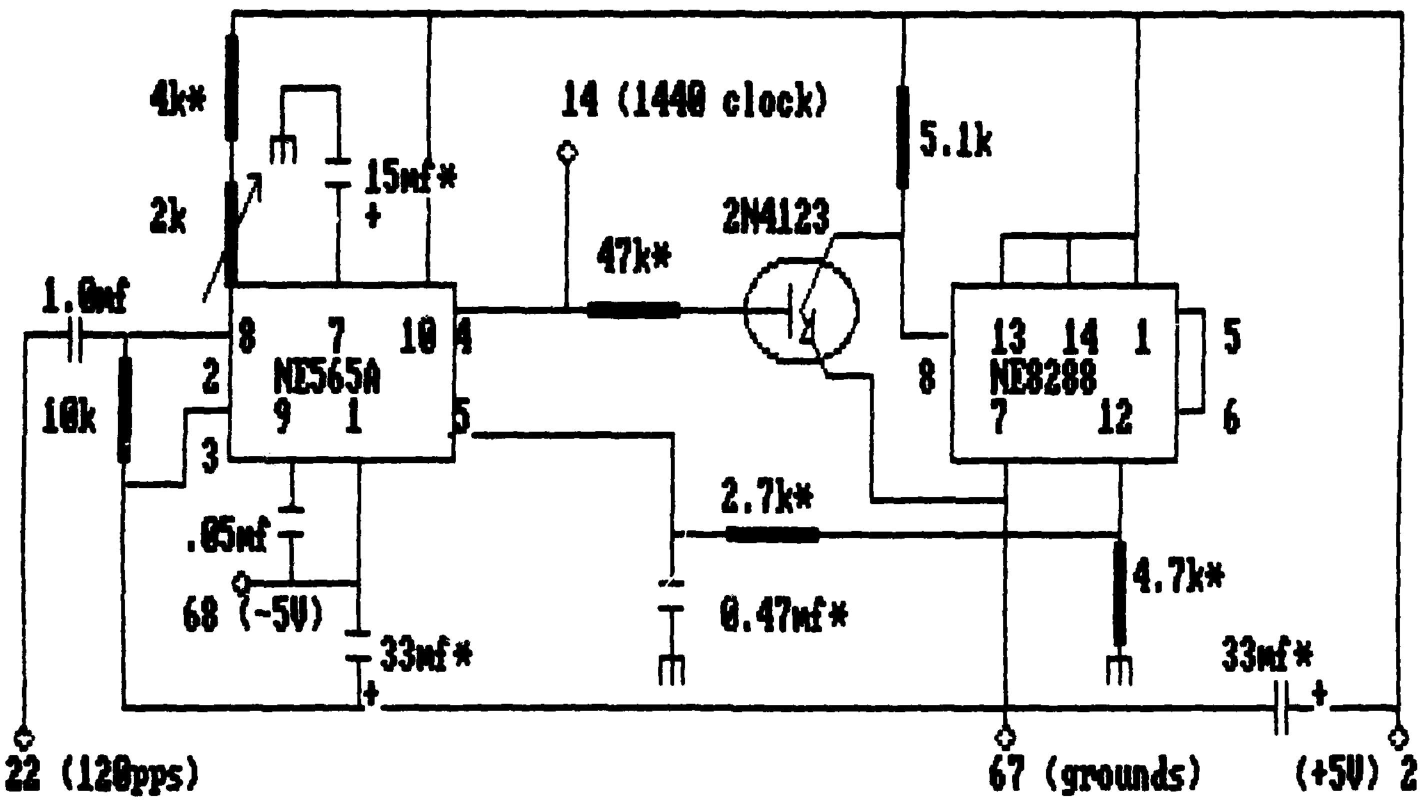

figure 1, 1440 hz master oscillator. * indicates changes.

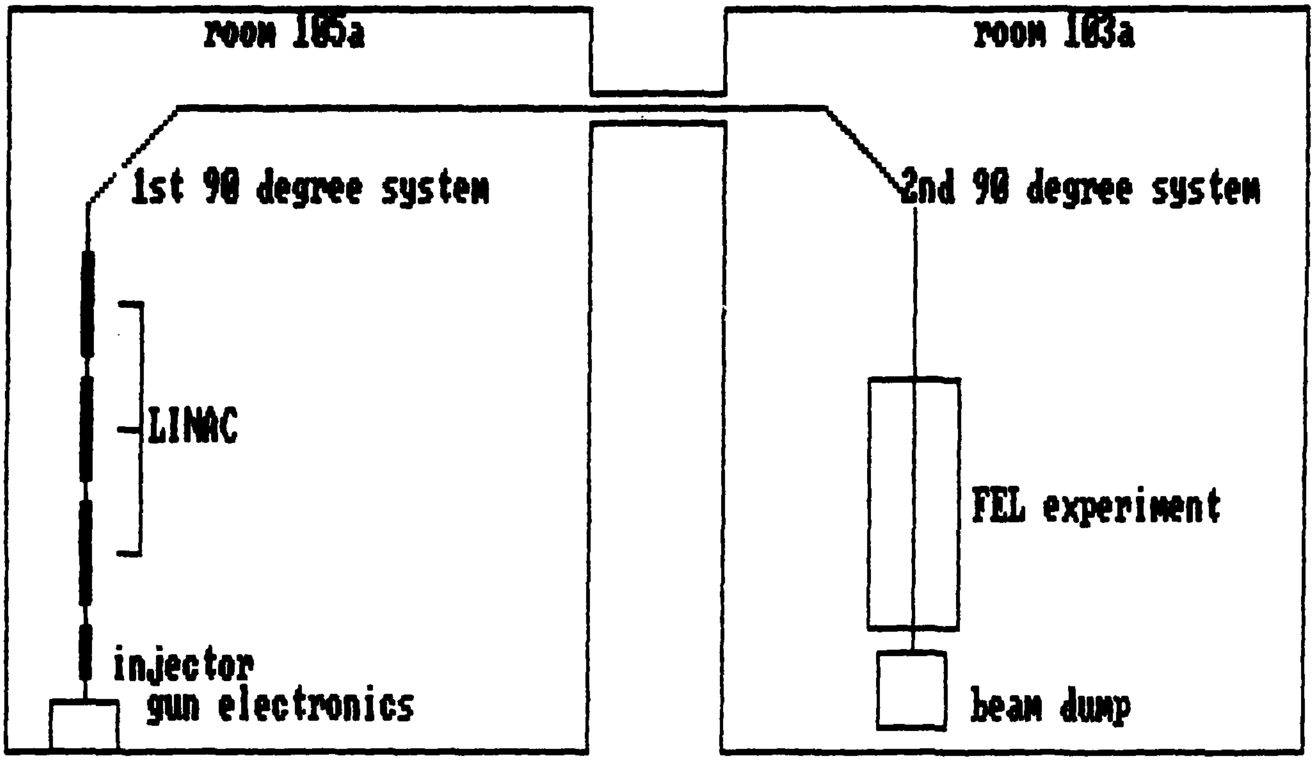

Figure 2 Layout of the LINAC and the FEL beam line.

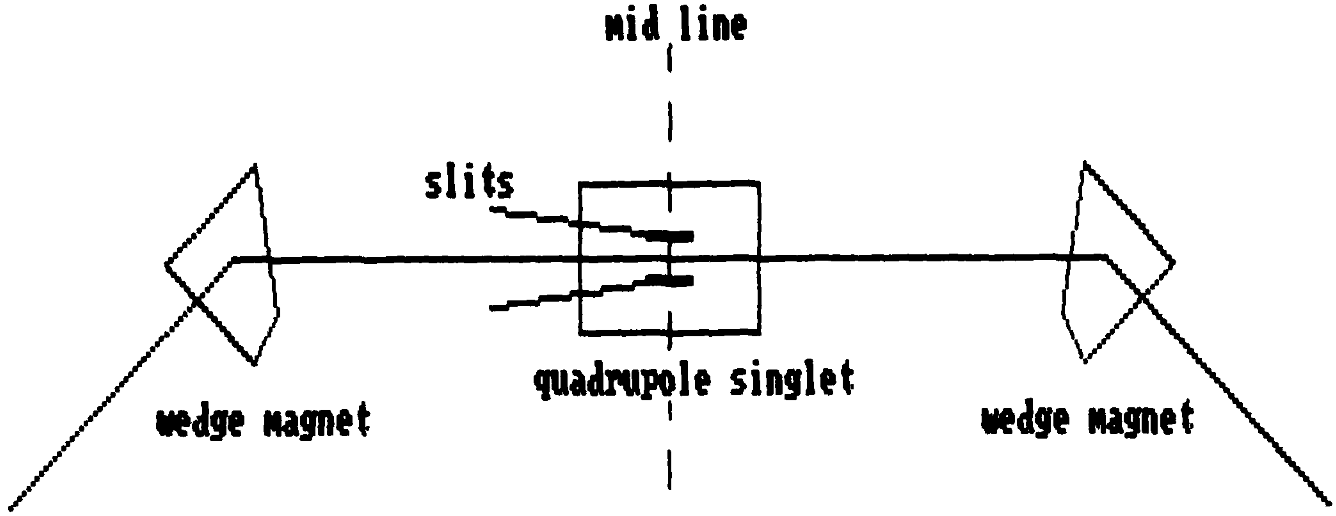

Figure 3 The 90 degree achromatic deflection system

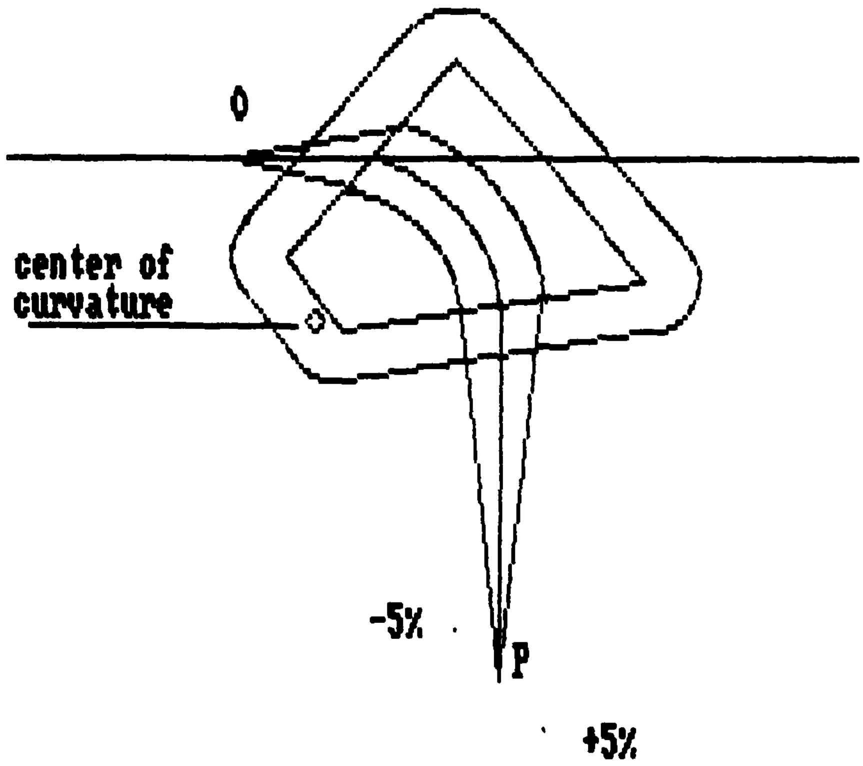

Figure 4 The beam dump magnet