PRACTICAL OPERATING PROBLEMS AT THE R.P.I. LINAC*

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Practical operating problems of an electron accelerator facility will be presented with their solutions. Organization, maintenance, and training problems and procedures will be presented in general. Klystron failures, thyratron replacement, and voltage standing wave ratio as technical problems will be discussed and their solutions documented.

The Rensselaer Polytechnic Institute's Linear Accelerator as an installed machine has been described fully in previous presentations.[1] Since the time of those publications, the Linac facility has grown in scope, accumulated many hours of beam time, expanded its staff and increased the reliability functions associated with a three million dollar tool. Describing an electron accelerator as a tool is perhaps oversimplifying the maze of electronic and mechanical components streching over 150 feet, and requiring a crew of men to operate, maintain and develop to its fullest potential. However, that basically is the definition of this apparatus, which permits experimenters to engage in the microscopic world of neutrons, radiation damage and effects, ion recoil and mass spectrometer studies, and other experiments that require a tool capable of producing electrons with energies from 10 to 70 Mev and peak currents to 2 amps. The purpose of this paper is not to delve into the deep technical aspects of an electron accelerator, but rather to present the experience gained on the R.P.I. Linac and the solutions to several practical problems. Aspects of operating this facility such as the basic organization, training program, maintenance procedures and operating problems will be discussed, in the hope that our solutions will provide possible avenues of thought for others in the field facing similar situations.

Organization

Academic facilities, especially those associated with research, tend toward a neoclassical or informal type of organization where individual behavior patterns are a dominant feature. To insure a more professional, efficient operation certain aspects of a formal organization must be injected. The interaction of these two kinds of organizations is always a real problem in any business system. Our organization problems are resolved by a formal project-orientated overall system, encasing an informal organization which can be diverted in any direction depending on the Linac needs.

The Linac portion of the Department of Nuclear Engineering and Science is organized in the following manner. Reporting to the Director of the site is the Supervising Engineer. He is responsible for the operation, maintenance, and development of the R.P.I. Linac, and for the electronic stockroom which is closely related to accelerator operation. He also acts as liaison between outside vendors desiring to buy time on the machine and the Director's office. This supervisor is assisted by an engineer whose prime responsibility is the continuous up-dating of the machine. He investigates, plans, designs and at times manufactures components which will develop the potential of the R.P.I. Linac so that it will be competitive to other machines and provide the experimental staff with desired parameters. The supporting staff consists of five operator-technicians. These men provide the varied services required to keep the machine at peak efficiency. They must build new circuits, repair breakdowns, both mechanical and electrical, and of course operate the accelerator. Working as a unified group they provide this operating service with 24 hour a day capability, five days a week. It must be obvious that the first practical operating problem is an adequate and extremely versatile staff. At R.P.I. we have a well-rounded and capable group of professional technicians. These five men, in addition to operating the machine, maintain the electronic stockroom, provide photography service at the site, and have, on occasion, scrubbed and

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painted contaminated floors. They are knowledgeable in vacuum techniques, cooling and heating problems, RF power and microwave electronics, and power supply and modulator repair. While the accelerator is in normal operation it is manned by one operator. The operator, who is responsible for the accelerator, works in conjunction with the crew chief who assumes the full responsibility for all phases of the operation in progress while on duty. During these operating periods, the remainder of the technicial staff is utilized on development or maintenance projects.

Training

To supplement the operating staff, a course in Linac operation is given to students and faculty who utilize the machine on a regular basis. The purpose of the course is twofold;

1. The students can serve as operators during vacation periods and at those times when all the technicians are required on development projects.

2. An experimenter who knows the machine intimately enough to operate it is more capable in designing his experiment to best utilize the machine.

At R.P.I. this training takes the form of a series of lectures presented once a year. The lecture series is divided into three parts; Accelerator design, R.P.I. Linac operation and Safety including electrical, mechanical and radiological. The lecture series, when completed, is supplemented by at least one week of on-the-job training. During this period, the student, under the tutoring of a regular operator, gains experience in the actual operation of the machine. Figure 1 shows a student being trained by an operator in console controls and components. In conjunction with the lecture and machine training, an operator's manual of over 100 pages has been edited and printed as a reference for all personnel who anticipate operating the machine. Through this extensive training program, there are now 17 faculty members and students who have qualified as part time operators and are capable of operating and performing minor repairs on the Linac.

Maintenance

A tool of this complex design requires two types of maintenance. Obviously, when a particular part of the system breaks down it must be repaired to continue operation. However, the second and less obvious phase of operation is preventive maintenance. Thru experience and careful planning of possible failure points, an extensive preventive maintenance schedule has been established which results in large savings of time and expensive equipment. At R.P.I. we allow a full eight hour day, usually Monday, in which men swarm over the entire machine, baking vacuum stands, checking voltages, oiling motors, changing filters, testing transformer oil potentials, repairing interlocks, changing drift pipe configurations for the next experiment, etc. Also, while the machine is off for maintenance, the Development Engineer may install a new piece of gear or improve an existing design. Strict adherence to the maintenance schedule is required and faithful performance has resulted in higher factors of reliability of the R.P.I. Linac.

Spare Parts

In conjunction with the maintenance program, another practical operating problem is a complete spare parts inventory. Nothing can be more irritating or time consuming than to trouble shoot a problem, locate the faulty component, and then not have a part to replace the failed item. The time lost while trying to obtain the part can result in hundreds of dollars of down-time. At R.P.I. we maintain an inventory of over 300 different components which we feel would remove the accelerator from operation if they failed. This number does not include small tubes, resistors, etc. or plumbing items, but transformers, klystrons, high voltage capacitors, chokes, etc., that are usually long lead time type of parts. We attempt to keep an up-to-date running inventory of quantity. This sometimes fails when, in the excitement and rush of repairing a component quickly in order to continue an experiment, the technician neglects to record parts that were used. The inventory cards also show part number, manufacturer, cost, and incoming orders. When development changes take place, obviously the spare parts inventory must change, deleting and adding as necessary. Surplus lists put out by various agencies are always investigated as a possible source of supply.

Outstanding Operating Problems

To discuss all the actual operating problems of the R.P.I. Linac would be lengthy and beyond the objectives of this paper. One outstanding and expensive problem of interest to other accelerator sites is the failure of the klystrons which are the final RF amplifiers. Our machine originally employed nine Litton L-3250 klystron tubes each capable of 10 MW peak power. Over the past few years considerable information has been accumulated on the failure of these tubes. Table I shows the present tubes that are in operation and their accumulated beam hours. Table II is a history of klystrons indicating the tube's serial number, beam time accumulated and cause of failure. The largest cause of failure has been due to oil contamination of the freon used to cool the windows. The oil contamination leads to carbon deposits on the windows causing local heating which in turn causes window puncture. After the mishap in March 1964, which was the second of this type at R.P.I., action was taken to minimize the window puncture problem. The following procedures were initiated:

1. Replacement of all components in the freon system that could produce hydrocarbons. For example, the rubber hose carrying freon to the klystron windows and to the accelerator input coupler windows. This hose was replaced with polyethylene tubing. This can be observed in Figure 2 going into the lead shielding box and originating from the overhead copper tubing which carries the freon to the klystron windows.

2. A complete cleaning of klystron windows, waveguides and coupler windows was undertaken. The windows were polished and washed with solvent while the waveguides and freon plumbing were steam-cleaned using a commercial unit. After the steam-cleaning the waveguides were swabbed out manually with solvent.

3. The lubricating oil in the freon blower unit was changed to a silicon base oil and sight glasses installed so that a periodic check of the oil level could be performed. This procedure was prompted by the first oil contamination mishap which was partially attributed to the loss of a seal in the freon blower.

4. Sections of waveguide were fabricated with two holes to inspect the klystron windows and waveguides without the time consuming effort of waveguide removal. In this scheme a light and mirror are put in one hole while an inspection is made visually through the other hole. Figure 3 shows the waveguide holes being utilized on a Monday morning. Periodic inspection of all klystron and coupler windows is accomplished as part of the weekly preventive maintenance schedule previously mentioned.

5. Consultation with suppliers of freon led us to specify super clean containers and valves. The freon is fed to the system through a regulator valve and this valve is also checked periodically for oil buildup.

6. The final step to minimize this puncture problem was the ordering of new klystron tubes, the Litton L-3944 which is the ceramic window version of the original tubes used at R.P.I. This new design does not require forced cooling of the output window, since its average power capability is considerably higher than that of the glass window of the L-3250.

As one can see by Table II, since these procedures were initiated last spring, not a single klystron has failed due to window puncture. We anticipate that by the end of 1966 all our klystrons will be of the latest design and the freon blower system will be replaced by a pressurized dry air system. As a summary to this problem; your observation is directed to Figures 4, 5 and 6. Figure 4 is of a clean glass klystron window. A new ceramic window is pictured in Figure 5. To give an approximate idea to the reader, Figure 6 shows a ceramic window in the input coupler of the accelerator with severe carbon tracks. Unfortunately no pictures are available of a dirty or punctured klystron window.

Other Operating Problems

Many of our other operating problems are related to reliability. Reliability is a measure of time lost and can be appraised in monetary terms. One such problem was the RF drive system originally provided on the R.P.I. Linac. Downtime averaging one to two hours a day was not uncommon. A comparison of the old and new systems is shown in Figure 7. Due to the large amount of "fan out" inherent in the design, a relatively high individual amplifier gain was required to provide enough signal to overdrive each klystron. To obtain sufficient gain the plate voltage of these tetrode amplifiers had to be raised to 6 kv. This is quite close to the maximum rating on the tube which is 7 kv. In addition, the failures of bypass capacitors in the cavities of these amplifiers caused severe on-line maintenance for plate voltages over 4 or 5 kv. By using an RF extractor system we were able to reduce this 6 kv plate pulse to 2 kv, thereby reducing failures and increasing our reliability factor. The extractor system is basically a piece of L band waveguide with loops rotated remotely by motors. The extractor system is placed at the output of klystron #1 and power is extracted by each loop which in turn supplies drive power to its corresponding klystron. A loop is also provided to supply RF power to the buncher. This scheme eliminated 9 driver chassis. The down time was reduced to an average of 2 hours per month which represents an increase in reliability by a factor of 15. One small problem encountered with this system was that the extractor loops could not deliver enough RF power to overdrive the klystrons. This condition was rectified by increasing the cross sectional area of the loops by a factor of 1.5. After this change, enough RF drive power was obtained to exceed the klystron saturation point.

The replacement of three 1257 hydrogen thyratrons by one ceramic water-cooled 7890 was the solution to another annoying and time consuming operating problem. We found that it is difficult to obtain satisfactory performance from 3 thyratrons over a range in repetition rates of 7.5 to 300 pps for the 8 usec cathode pulse, and 7.5 to 720 pps for the 4 usec cathode pulse. The initial problem develops in attempting to decide which of the 3 thyratrons is mis-firing. Then experimental changes must be made to the reservoir voltage to alleviate the particular situation. We experienced good life statistics from the three 1257 tubes but the delicate and frequent adjusting that was necessary expended valuable time. Good results have been obtained using the new ceramic tubes. At present five of our nine modulators have been converted to utilize this water cooled thyratorn. The remaining modulators will be modified as the 1257 tubes fail. A minimum amount of time is necessary to adjust the 7890 for satisfactory performance. The manufacturers specifications are imprinted on the tube and in 80% of the installations the tubes functioned correctly when triggering was applied. In only one case was a slight change in reservoir voltage required. The life test statistics on the 7890 are also excellent. They show only two failures to date. One tube accumulated in excess of 2000 hours of operation time, and the second tube failed after 500 hours due to an open filament.

A continual source of vacuum problems exist in the form of leaks at any of over 100 connections on the machine. When a section of drift pipe is frequently being removed and then re-installed, the probability of a leak at the joint increases. Changing the drift pipe length is required to accommodate special experiments at the R.P.I. Linac as we change target stations. The aluminum conoseal joints on the drift pipe are not sufficiently durable to withstand repetitive resealings. As a consequence, the problem of obtaining a satisfactory vacuum after a drift pipe change often required excessive time. To minimize this vacuum problem, new flanges using an O ring have been designed. A special feature of the design is the use of a large flange which will place the O ring one inch from the beam pipe and two inches from the center of the beam. This should reduce the radiation damage considerably. Two such mating flanges have been installed for over a month. Periodic examination of the O ring has shown no deteriation from radiation. No outgassing of the O ring has been observed. Since their installation, these flanges, though disassembled 10 times, are still leak tight. Plans to install additional flanges of this type will proceed if we continue to achieve these positive results.

Another problem which had a simple but expensive solution is the high VSWR observed in the accelerator waveguide sections; especially the first section. The frequency range over which the Linac is tuned, based on two years operating experience, varies from 1300.00 MC to 1300.300 MC. VSWR'S as high as 1.7:1 have been measured. Possible damage to klystron windows as a result of the high VSWR prompted us to arrange for two ARCO engineers to come to R.P.I. The expectation was that through their microwave testing technique they could adjust the section to reduce the VSWR value. At the completion of tests, their recommendation was that the problem could not be resolved at our site. They suggested that a factory adjustment to the cavity wall in the waveguide section would alleviate the problem. Weighing all factors, it was decided to order a new section with the desired specifications on VSWR value. This solution will provide the R.P.I. Linac with 10 MW of ripple free peak power in the first section. The existing first section will be shipped to the ARCO factory for adjustment upon receipt of the new waveguide section. Upon its return, another section with high VSWR will be removed and shipped to ARCO for adjustment. With this rotational system in effect, the eventual result will be 9 sections in operation and 1 spare, all with a low VSWR.

In conclusion, I again state that there is neither time nor space to discuss all the varied operating problems experienced on a machine which operates 3000 hours a year. Emphasis has been placed on problems thought to be of major interest to other accelerator personnel. Their solutions are by no means unique, but since the results are satisfactory thru experience, they have been presented and documented as an aid to those with similar problems.

References

1. E. R. Gaerttner, M. L. Yeater and R. R. Fullwood, "Rensselaer Polytechnic Institute Linac Facility" Neutron Physics 1962.

TABLE I

KLYSTRONS IN OPERATION

Klystron Serial No.	Location	Date Installed	Total Beam Hours 2/4/65
136 (R)	1	10-23-63	4125.3
102	2	4- 5-63	6265.6
2 (C)	3	11-17-64	458.1
190	4	10-21-63	6531.7
107 (R)	5	2- 3-64	2913.1
437 (R)	6	8-13-64	1168.9
72 (R)	7	1- 7-64	3002.3
3 (C)	8	11-19-64	391.3
1 (C)	9	10-17-64	563.6

(R) - Rebuilt

(C) - Ceramic Window

TABLE II

KLYSTRON HISTORY

Serial Number	Why Failed	Date Failed	Total Beam Hours	Disposition
91 (R)	---	12-30-63	2170.5	Spare
88 (R)	---	11-19-64	1970.5	Spare
127 (R)	---	11-17-64	1879.7	Spare
60	Arcing	9- 2-62	1085.5	Not Reworkable
136	Window Puncture	4- 5-63	1127.5	Rebuilt
127	Shorted	6-20-63	2071.2	Rebuilt
72	Window Puncture	7- 1-63	1871.1	Rebuilt
91	Cathode Insulator Puncture	9-18-63	2341.7	Rebuilt
345	Window Seal	12- 9-63	457.2	Not Reworkable
107	Window Puncture	1- 7-64	2622.4	Rebuilt
88	Sparking & Low Power	2- 3-64	3198.7	Rebuilt
127 A	Window Puncture	3-16-64	861.4	Rebuilt
92	Window Puncture	4-23-64	4185.1	Rebuilt
437	Excessive Sparking	6- 5-64	2553.9	Rebuilt
92 A	Excessive Sparking	8-12-64	204.1	Not Reworkable

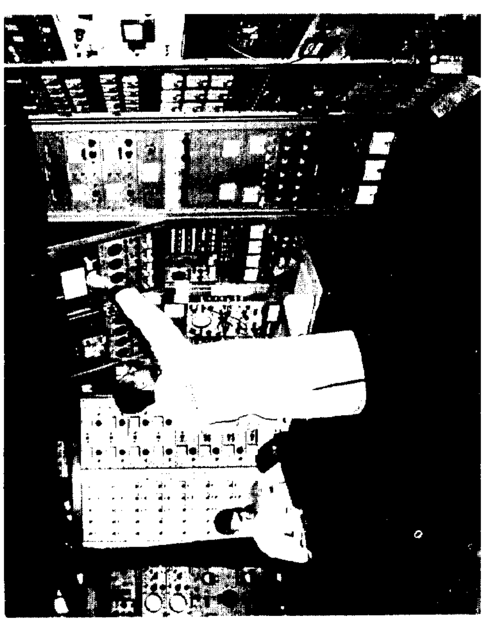

Fig. 1. Student learning console controls and components from experienced operator.

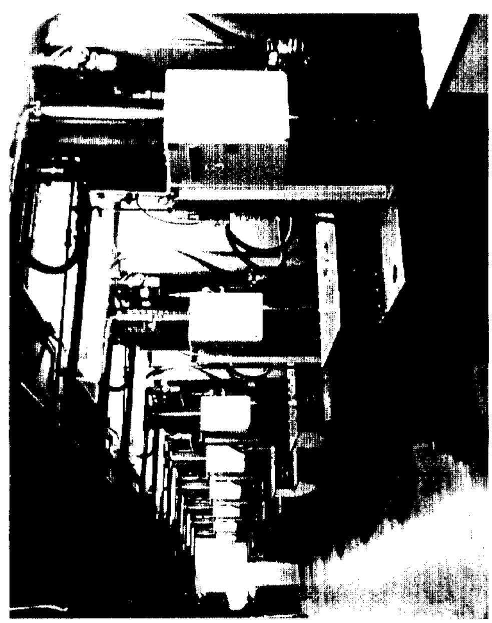

Fig. 2. View of klystron and modulators showing polyethylene tubing for freon.

Fig. 3. Technician inspecting klystron window through observation port.

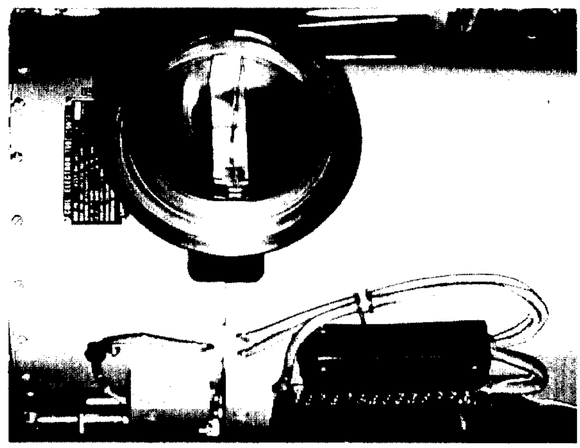

Fig. 4. Clean glass window of L-3250 klystron.

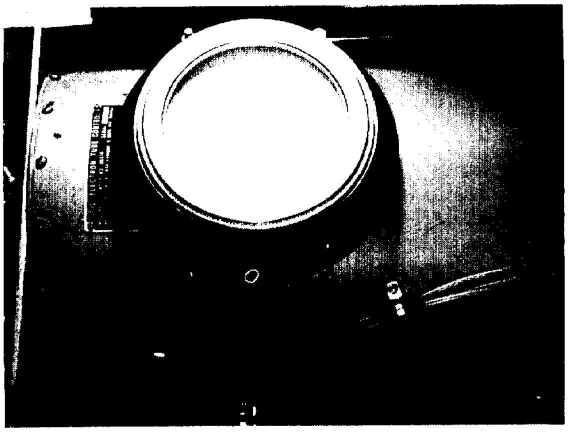

Fig. 5. Clean ceramic window of L-3944 klystron.

Fig. 6. Dirty input coupler window with carbon tracks.

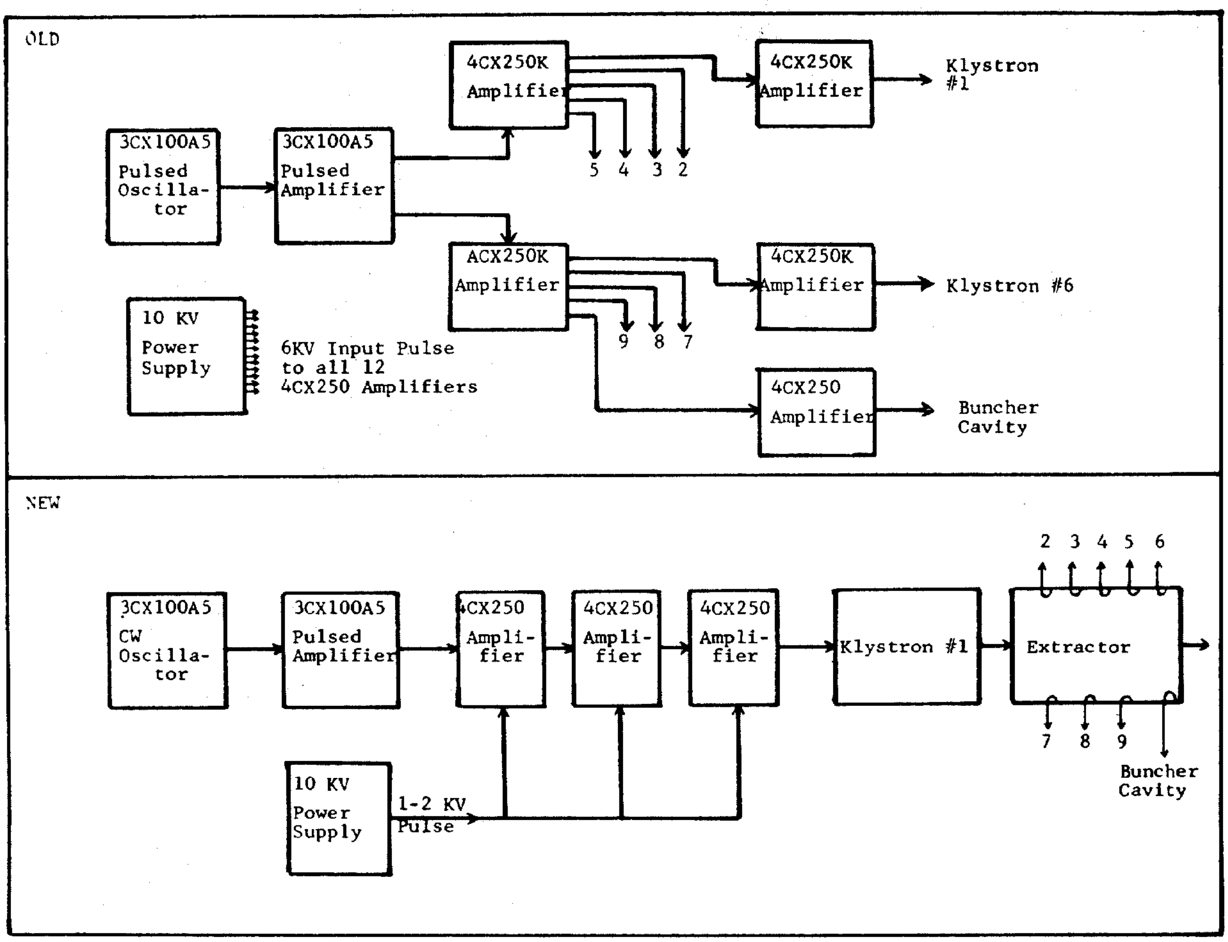

Fig. 7. Comparison of old and new RF driver system for R.P.I. Linac.