LINAC OPERATIONS AT FERMILAB

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Abstract

The Fermilab Linac has been delivering unprecedented amounts of beam for HEP. The addition of Main Injector, three high intensity high repetition rate experiments and the 120 GeV Fixed Target Programs have increased the repetition rates from 0.33Hz. to a maximum of 7.5 Hz. and it is expected to increase further. The intensity accelerated by the Booster is 5 E12 protons per pulse. The effects on radiation levels and operational reliability and developments helping both to cope with the higher rates and make the beam more useful to Booster will be discussed.

THE PROBLEM

As the demand for higher booster intensity and repetition rate began to ramp up, the Booster was operating at about 65% efficiency. Because the Linac discards the first ten μsec of beam it needed to accelerate almost 1 E13 H- ions per pulse. Today after many improvements to the Linac and Booster, booster efficiency is 90% and only 7.7 E12 per pulse are required from Linac.

IMPROVEMENTS

In the late 1990's Milorad Popovic [1] accurately modeled the high energy linac quadruples. Using this data he was able to make significant reductions in losses. The match to the Booster was also improved.

In 2001 an experiment [2] was performed measuring the effect of linac beam current on booster efficiency. At that time the Linac normally accelerated 50ma. and injected 11 turns into the Booster. During the experiment, linac beam current was reduced to 30ma. and The Booster was tuned with up to 20 turns injected. The Booster operated at the same or better efficiency at the lower current. As a result, linac beam current was reduced to 40 ma. and as a result of further booster improvements to 36 ma.

As a result of these improvements, linac beam losses have decreased dramatically. The parameter D7LMSM is the sum of all the loss monitors in the RF area. In 2000 D7LMSM was >20. The improvements noted plus constant tuning has reduced the total losses to the 10 to 12 region for the H- ion source and less than ten for the I- ion source.

To get a better measurement of the linac energy on a day to day basis a device called the Velocity Meter [3] has been installed in the 400 MeV Line. By measuring the beam phase between two Griffin [4] detectors it measures flight. While it is not calibrated in energy, it does alert one to energy changes. Before this monitor was installed it was impossible to determine if an energy drift was causing booster efficiency to decline.

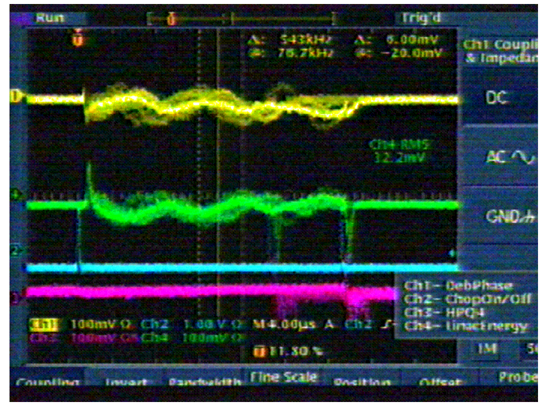

Figure 1: Velocity meter scope traces.

The output signal (in green) viewed on an oscilloscope can detect an energy swing during the pulse or an overall energy shift. The computer reads this parameter and automatically changes the RF phase in the final RF module to correct the energy. Using this method has stabilized the linac energy and made booster tuning more repeatable.

A Bunch Length Monitor [5] was also installed in the 400 MeV Line. It has been empirically determined that booster needs this device to read less than .85 nsec. for good operation. Linac has been tuned so that it averages approximately .83 nsec. The low energy buncher. medium energy buncher and the phase difference between the Low Energy Linac(LE Linac) and High Energy Linac(HE Linac) are the most common adjustments to control this.

CONTINUING PROBLEMS

Looking at the trace in Fig. 1 one notices an oscillation. The oscillation is at approximately 130 kHz and is a real energy effect. We can see this in the HE Linac RF phase and at times in the gradient. There is a program underway, lead by Ken Quinn, to locate and repair the source of this oscillation.

There is a slow drift of some parameter in the LE Linac. The signature of this drift indicates that it is RF related. The gradients have independent readings but intertank phase does not. The drift does not appear to be the gradient because the independent readings do not change at the same time. The lack of independent readings has made looking at phase difficult. The fix is to vary the phase of LE Tank 5. This both changes the output energy of the LE Linac and the phase difference between the LE Linac and the HE Linac.

As mentioned earlier the Linac discards the first 10μsec. of beam each pulse. This is the time it takes for the feedback systems in the LE Linac to settle in. During this time the beam is unreliable and dumped. This beam usually has slightly higher losses than the later beam sent to booster and should not be necessary. The HE Linac settles in about two μsec.

To address the LE RF drift and the 10 μsec. throwaway there is a program ongoing to replace the LE Linac LLRF System [6,7]. The new system replaces the current Intertank Phase Error reading with a phase measurement between the cavity and reference line. This will provide proper read-backs and control of the amplitude and phase of the RF. It will hold the accelerating gradient to within .3 percent and the phase being held to less than .3 deg. and settle in two μsec. The effect of this will be to eliminate the LE Linac RF drift and cut the 10 μsec. of beam thrown away to two μsec. These improvements improve linac stability and losses.

RELIABILITY

Overall linac reliability has decreased over the last few years. Before the upgrade in 1993 uptime was 98%. So far in 2008 it is 95.6%, in 2007 it averaged 94.8%. Over the period of Run II from 2001 to 2005 it was 97%. From June, 2006 through August, 2008 it was 95%.

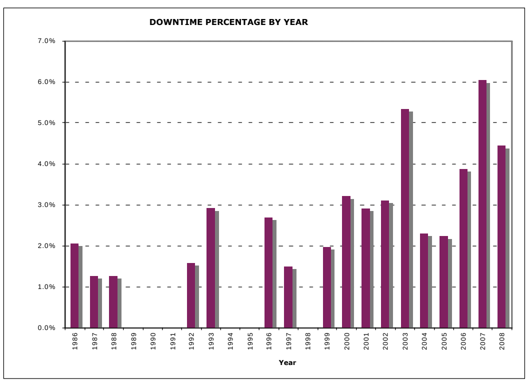

Figure 2: Linac downtime percentage by year.

In the time period of 2001 through 2005 there were 1160 hours of downtime or 3.03% of the total scheduled time from 6621 entries. In the period from June 2006 through August of 2008 there are 908.5 hours or 5.035% on 4986 entries.

Table 1: Percent of Downtime By Major Subsystem.

	2001-2005	2006-2008
LRF TOTAL	36.78%	38.77%
KRF TOT.	32.92%	19.55%
PREAC	8.38%	10.78%
MISC. TOT.	19.27%	28.34%
SAFETY	1.10%	1.17%
CONTROLS	1.45%	1.39%

Table 1 shows the distribution of downtime by major subsystem. The differences are small between the 2001-2005 and 2006-2008 time periods. There are however more incidents of longer duration in the 2006-2008 time period. There were an average of 131 events per month from 2001 to 2005, while the average for 2006 to 2008 is 191.

There are several reasons for the decrease in reliability. Components are aging and require more maintenance. The retirement of a the last technician who was here from the beginning The decrease in the lifetime of some components coupled with Fermilab's policy of not scheduling regular maintenance periods.

The water flow meters for the Klystron RF Systems are an example of aging components. They operated without major problems for several years, but are now sticking and causing the systems to trip. Each trip causes from 2 to 5 minutes of downtime.. A program to replace them has been going on for some time with limited success.

In the period around 2001 to 2003 the lifetimes of the 7835 triodes decreased dramatically. There was a time when the lifetime was less than the time needed to build or rebuild them. Fermilab had to borrow tubes from other laboratories to continue operating. The manufacturer, Burle Industries, has made great strides in modernization and quality control. As a result, average lifetimes have increased but there is still a wide spread in tube lifetime. While not back to the pre 2000 levels, the last few years have shown an upward trend.

The policy of not scheduling maintenance periods also contributes to lower linac reliability. While this maintenance policy does work for the laboratory as a whole, there are so many users that the Booster must be broken for Linac to get maintenance time. The result is that the Linac has trouble stretching problems until a maintenance period.

Most linac downtimes are less than two minutes. Since June, 2006 downtimes of two minutes or less account for 61.25% of the total entries. Events lasting 14 minutes or less account for 90% of the total number of downtime entries. Forty six percent of the total downtime results from entries of less than 2 hours. Some serious problems do not always result in one long downtime but can be many short ones.

A recent example of this type of problem was a long series of Klystron Charging Supply Trips. The downtime from each was generally less than four minutes. The frequency started out low, one or two trips per day, and ramped up to as many as nine per day. The problem took almost six months to get to the point of being noticeable. It turned out that the temperature in the charging supply was to low causing the ignitron to self-fire. The total cost was 39.2 hours down on 1096 incidents.

SUMMARY

The Fermilab Linac has been made to run in a way that makes it possible for the Booster to operate very efficiently. These improvements are mostly the result of diagnostics developed by the Booster Group. Using these diagnostics, both in automatic loops and manual tuning, has stabilized the Linac. The underlying problems are still there but we now have solutions in progress and are close to being able to implement them.

REFERENCES

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