IMPROVEMENTS TO ISIS RF CAVITY TUNING

R.J. Mathieson, D. Bayley, N.E. Farthing, I.S.K. Gardner, A. Seville, STFC
Rutherford Appleton Laboratory, Chilton, Didcot, U.K.

Abstract

This paper describes work improving the performance of the ISIS RF cavity tuning system by introducing better identification of the tuning loop transfer function used to correct the residual tuning error. The iterative process to remove residual cavity tuning errors is improved by varying the transfer function across the acceleration cycle.

INTRODUCTION

The ISIS facility at the Rutherford Appleton Laboratory in the UK routinely accelerates proton beam currents in excess of 230 uA to run two neutron spallation target stations. The accelerator consists of a 70 MeV H- linac and an 800 MeV, 50 Hz, proton synchrotron. The synchrotron beam is accelerated using six fundamental (h=2), and four second harmonic (h=4) ferrite loaded RF cavities each having its own drive amplifier and bias system. Each RF cavity is driven as a high Q tuned RF circuit; the resonant frequency being controlled by biasing the ferrite using a current generated by the bias regulator system.

The ISIS Low Power RF (LPRF) systems use the 'classic' reactive compensation tuning method [1]. This utilises a bias control loop fed by a phase detector between the final stage amplifier control grid voltage and the gap volts measured by a capacitive divider. A block diagram of the tuning system can be seen in Figure 1.

The cavity tuning control loop is insufficient to achieve the desired tuning performance, so an iterative process is then applied to modify the 50Hz tuning demand function to reduce residual tuning errors. This technique is performed by software known as CavTune.

CAVTUNE

The CavTune software has a long history on ISIS, the current version being an IDL program developed from the original GRACES code created by I.S.K. Gardner. The residual cavity tuning phase detector error is digitised using a National Instruments PXI, averaged over a specified number of samples. This error is then transformed to the frequency domain, corrected by the estimated transfer function of the tuning system in the frequency domain, $G(j\omega)$, before being transformed back to the time domain and subtracted from the tuning demand signal. Applying this process iteratively is very successful at removing the low frequency components of the residual phase error; however, higher frequency errors are often introduced and compounded by further iterations. For this reason, CavTune use is usually limited to frequencies below 10 kHz, and to a small number of iterations.

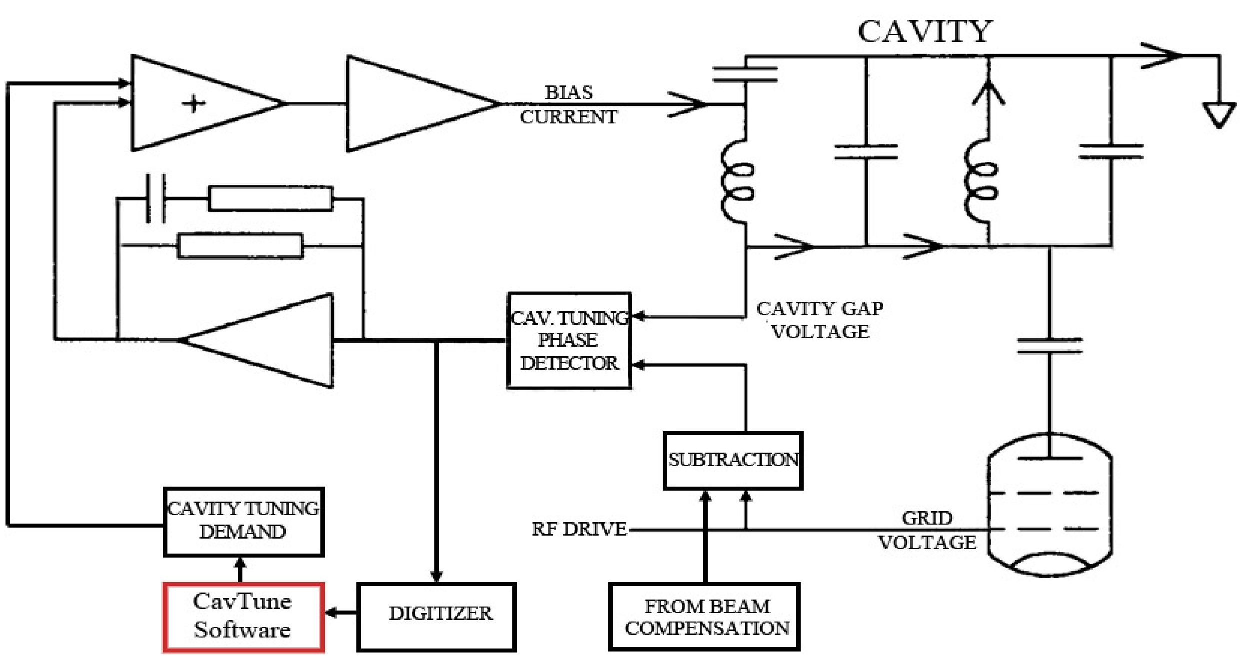

Figure 1: Block diagram of the ISIS Cavity tuning systems.

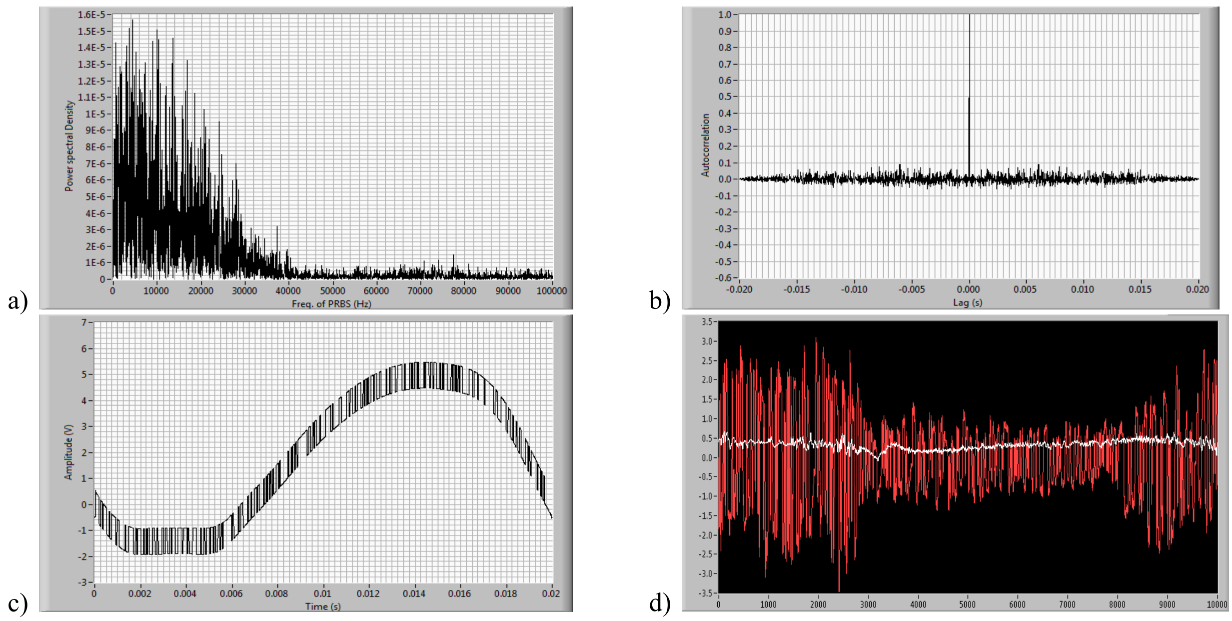

Figure 2: PRBS System Identification up to 30 kHz - a) PRBS autopower function, b) PRBS autocorrelation function, c) Exaggerated PRBS applied to the tuning function, d) Phase detector error from PRBS stimulus (red).

The main error in the CavTune process stems from the current estimation of the system transfer function. A single transfer function for the entire cycle is taken from measurements at only nine frequency points, with linear interpolation used to estimate the full function. Improved measurement of the second harmonic transfer functions has allowed tuning corrections at higher frequencies and with less iteration. This process is known as system identification.

System Identification using PRBS

Traditional system identification involves exciting the system with single frequency sinusoids or a step function. However for identification of the tuning loop a pseudo random binary sequence (PRBS) is recommended as the most suitable stimulus for system identification [2]. A random signal has certain advantages over other techniques:

- The power density spectrum $\Phi_{uu}(j\omega)$ is roughly constant over a wide range of frequencies, allowing accurate measurement of the transfer function over a large frequency band.
- The autocorrelation function $R_{uu}(\tau)$ is an impulse, meaning it is non-periodic and will be uncorrelated with the demand signal, unless the demand contains random noise. It can be seen as adding 'known noise' to the system.

If carefully chosen, a PRBS stimulus behaves like the ideal random signal described above. It is of particular importance to ensure the spectral power density is sufficient in the frequency band of interest to prevent noise in the measured response dominating. In practice it was found most effective to generate many signals, select those with the most suitable spectral content, and average results from several signals. Typical auto power and correlation functions are shown in Figures 2a & 2b.

A 0.05 volt PRBS signal, $u(t)$, was added to the tuning loop demand and compared to the resulting response on the tuning phase detector, $v(t)$, shown in Figures 2c & 2d. With no correlation between the demand and stimulus, the transfer function in the frequency domain is given by the ratio of the cross-power spectral density of u and v to the auto-power spectral density of u [3]:

$$G(j\omega) = \frac{\Phi_{uv}(j\omega)}{\Phi_{uu}(j\omega)}$$

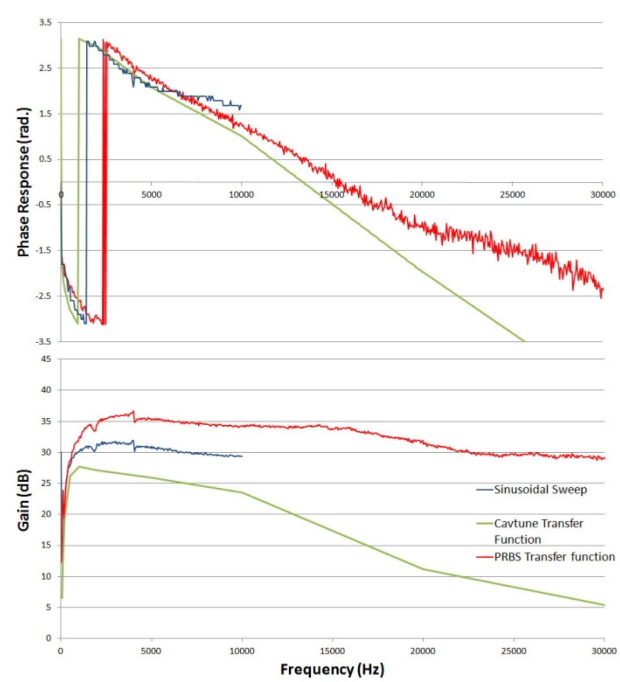

Figure 3: Results of PRBS system identification.

The results of PRBS system identification alongside those of a purely sinusoidal sweep with a gain and phase meter (up to 10kHz), and the transfer function used by CavTune are displayed in Figure 3. The CavTune function is much lower in amplitude due to an arbitrary scaling applied as a user defined variable in the IDL software. It can be seen that the results from the PRBS and the sinusoidal excitations match very closely, but the CavTune function deviates at higher frequencies. The PRBS have initially been chosen to concentrate power spectral density in the low frequency region up to 30 kHz. However, it will be possible to extend the reliable transfer function by combination with measurements concentrated at higher frequencies.

A PRBS stimulus has also been used to measure the variation in system response throughout the 20ms acceleration cycle. Figure 4 shows the gain and phase response taken at 2ms intervals throughout the cycle from 1ms PRBS stimuli. The gain response is seen to be varying by up to 25dB across the cycle and the phase response diverges by over 2 radians above 10 kHz.

The 0.05 V PRBS signal results in a peak phase error of around 20°, with the system recovering in 2 ms. Using the existing setup, the amplitude of the PRBS could be reduced by an order of magnitude, suggesting it could be possible to measure the tuning transfer function under beam conditions with this method. This will be attempted in the next available machine physics period.

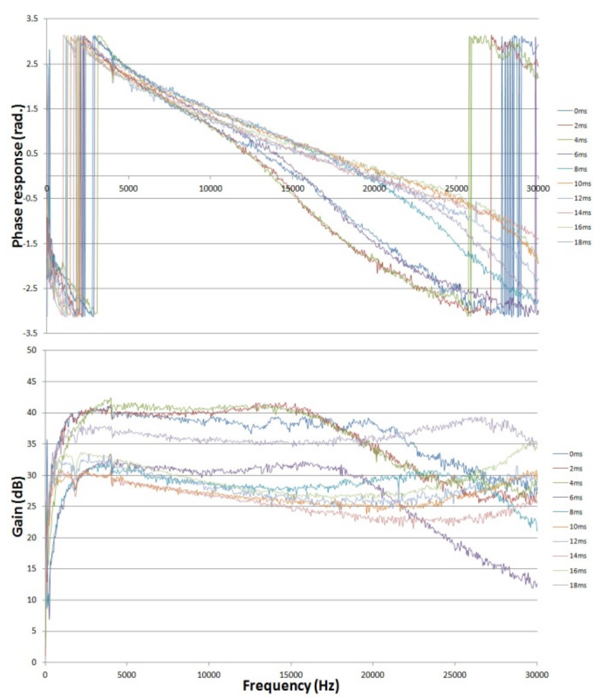

Figure 4: Cavity tuning transfer function variation throughout the acceleration cycle.

Improved CavTune

A new CavTune program has been developed in National Instruments LabVIEW. In addition to the CavTune function, some improvements have been made to the code:

- System identification can be performed using either PRBS or Schroeder-phased harmonic stimuli [2].
- Separate transfer functions can be applied for errors in different parts of the acceleration cycle. Effectively varying the transfer function with time.
- Problems with discontinuities at the function wrap-around point have been improved.

The results of tuning using the two CavTune programs on a second harmonic system can be seen in Figure 5. The new program is effective at correcting the high frequency errors introduced by the original CavTune. Bar transients at beam extraction and the function wrap around, the phase error is kept below 10°.

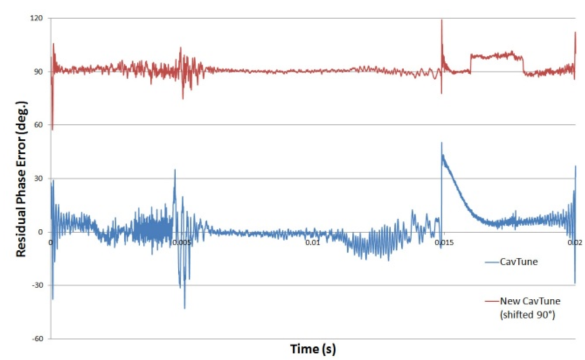

Figure 5: Residual phase error from original and new CavTune software.

CONCLUSIONS

System identification using PRBS has proven to be an effective method of acquiring the cavity tuning transfer function. By utilising a time varying transfer function, the residual error left by the cavity tuning loop has been reduced below 10° across the acceleration cycle. With the possibilities of extending the transfer function to higher frequencies and applying system identification under beam conditions, the software could be improved further.

REFERENCES

[1] F. Pedersen, "A Novel RF Cavity Tuning Feedback Scheme for Heavy Beam Loading" PAC1985, Vancouver, May 1985, http://www.JACoW.org

[2] L. K. Mestha, C. W. Planner., "Application of System Identification Techniques to an RF Cavity Tuning Loop" EPAC1990. Nice, June 1990 http://www.JACoW.org

[3] L. K. Mestha, RAL Technical Report.41,.89-101, September 1989