Improvements in Vessel Impedance Measurements at Daresbury

S.F.Hill and M.J.Pugh
DRAL Daresbury Laboratory, Daresbury, Warrington WA4 4AD, UK

Abstract

The RF impedance of all vessels is routinely measured prior to their installation in the SRS storage ring. A great variety of chamber geometries must be handled and the work is often carried out under tight timescales. As part of upgraded features a new PC-based system has been obtained and software written using the graphical environment LabVIEW® to acquire data from a fast sampling oscilloscope, which will allow a very flexible method of information handling and interpretation. The mechanical arrangements for time-domain impedance tests are also being upgraded with the change from a test vessel plus impedance launching cones, together with an approximate reference vessel and cones, to a single set of accurate impedance transformers which will be used to characterise both test and reference vessels, eliminating impedance matching errors between the two vessel systems.

1. INTRODUCTION

The SRS straight sections comprise many complicated geometry vessels with a large number of internal components fitted in. All straight section vessels are assessed for their likely impact on the electron beam before installation in the storage ring. This is in the form of simulated electron beam bench tests to acquire data on the production vessel, both as a quality assurance system (e.g. identifying spring fingers out of place) and to measure the parasitic loss parameter, and thus estimate the broad band impedance contribution. Only straight section components are measured at present.

Recently, a large number of vacuum vessels have had to be tested: both new vessels constructed for the re-arranged lattice to accommodate the second superconducting wiggler magnet [1,2,]; and also where vessels have failed in some way, mainly due to vacuum leaks at absorber water feed-through flanges. Altogether, some 8 D- and 5 F-Quadrupole magnet vessels, together with 3 new injection kicker magnets and a redesigned septum have needed to be tested under very tight schedules. This brought to light some problems in the testing system and its analysis, the solutions to which are detailed here.

2. MEASUREMENTS AND APPARATUS

All impedance related measurements at Daresbury are made directly in time domain. The system used consists of a Tektronix 7854 sampling oscilloscope with GPIB data bus facility, in which is fitted a 7S12 Time Domain Reflectrometry (T.D.R.) insert. This is configured with an S52 step pulse generator ($t_r \leq 25$ ps) and an S6 sampling head ($t_r \leq 30$ ps). T.D.R. is used on each vessel with the above system, which has been useful in identifying incorrectly fitted bellows shields and spring fingers not making contact across metallic surfaces. T.D.R. waveforms are now saved in a central store which allows easy retrieval for cross-vessel comparison. Loss parameter measurements are made using an Impulse Forming Network (I.F.N.) [3] which produces a near gaussian output pulse by differentiating a fast step input pulse. This allows a simulated beam measurement to be made with a ~20ps σ, which is the theoretical SRS bunch length at the injection energy of 600 MeV.

The actual method used to calculate the loss parameter has been described elsewhere [4,5] and is summarised below :-

The loss parameter k(σ) is calculated from :-

$$k(\sigma) = \frac{2Z_o}{Q^2}\int_{-2\sigma}^{+2\sigma} I_o(I_o - I_s)dt \qquad (1)$$

where I_o = Current pulse launched through an ideal vacuum vessel (the reference vessel)

I_s = Current pulse launched through the vessel under test

Z_o = Characteristic Impedance of the coaxial line section

and $Q = \int_{-2\sigma}^{+2\sigma} I_o dt$ = charge in the reference vessel pulse

and the broadband impedance contribution is estimated using a model of a Q=1 resonator centred at the cut-off frequency of the SRS beam pipe (~ 2 GHz).

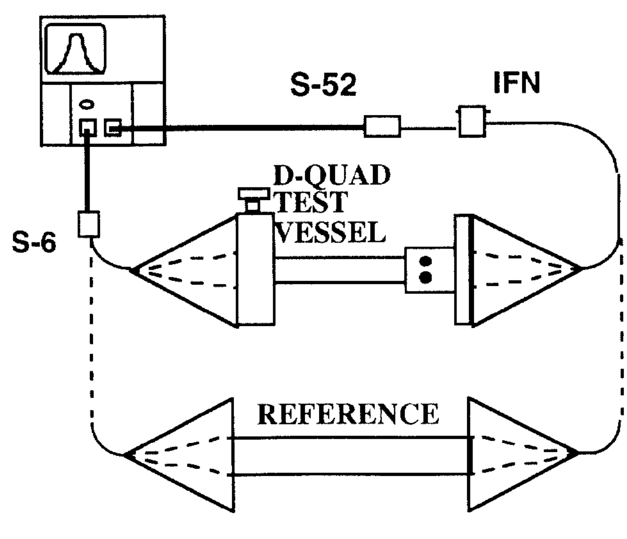

Figure 1. Present Vessel Measurement System

The physical system used up to now is shown above. A pulse is launched through the test vessel and data collected by the sampling scope. The connections are then transferred to the reference vessel and the data saved. This is repeated several times.

Separate assemblies have been used, with two sets of cones (the pulse launchers which transform the characteristic impedance from 50Ω up to that of the vessel). The central conductor used is 4.8 mm diameter copper rod. The outer cone is far too large for the SRS-2 D-Quadrupole vessel, having been made for a much larger aperture vessel for SRS-1. A thin steel liner cone is inserted in the outer cone, to transform the outer diameter to the 75 mm of the reference vessel. Figure 2 shows T.D.R. data taken of the reference vessel, expanded to show the vessel detail.

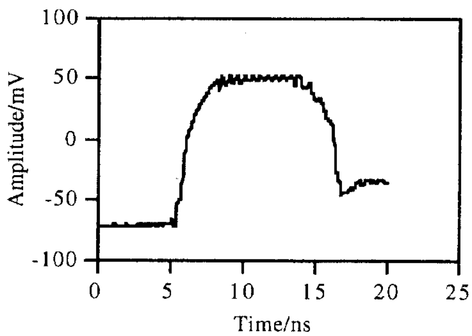

Figure 2. TDR Data from Reference Vessel

Note that since the cones taper linearly with length, the impedance change (= amplitude here) is non-linear. Also the effect of poor cone-vessel matching can be seen as an amplitude ripple on the flat top reference vessel pipe section. This is due to the both the flimsy inner cone and a high dielectric centre rod support.

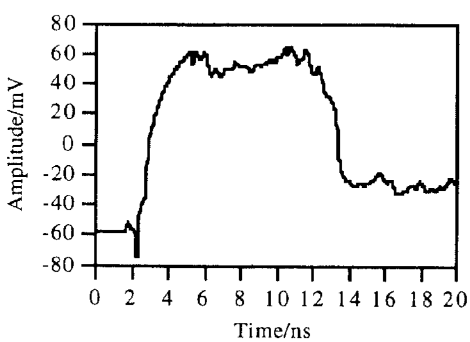

Figure 3. TDR Data from D-Quadrupole Test Vessel

Figure 3 shows T.D.R. data from an SRS-2 D-Quadrupole vessel, and shows very well some of the problems encountered with the present system : the problem of matching the centre conductor to a 50Ω SMA centre pin (shows as a dip prior to the rise in impedance) which can be minimised by moving the rod back and forth to centre it in the vessel; and the mismatch from the cone to the vessel, which shows as a dip from the wider cone down to a smaller diameter main vessel section.

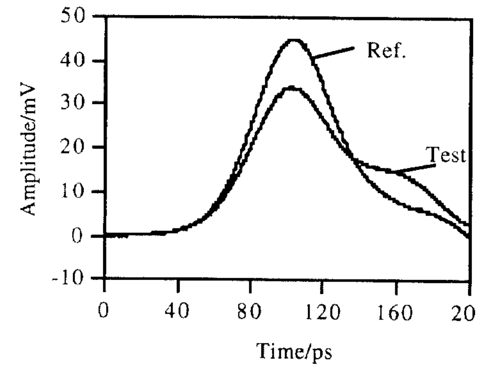

Figure 4. Gaussian Pulse Data for a D-Quadrupole Loss Parameter Measurement

Figure 4 shows the analysed waveforms obtained from a vessel using the arrangement of Figure 1. This data is analysed using a PC in conjunction with the 7854 waveform maths capability, as described below.

3. COMPUTATIONAL IMPROVEMENTS

An IBM XT computer was used for simple data acquisition using a BASIC program to drive a GPIB card. The limited memory and storage facilities on this machine prevented graphing/printing of results. A program WFORM [6] was written to perform some analysis on the gaussian pulse data, but had to be pruned considerably to allow it to fit within the available memory.

3.1 *WFORM*

Since it is the real part of the loss parameter which is used when calculating the impedance, the imaginary contribution (which shows as a delay between reference and test waveforms) must be removed. WFORM does this by aligning the curves, using the rising knee. It actually takes up to 10 waveforms each from test and reference vessels, and after averaging and time aligning, produces the two main outputs required for the calculation, together with a complete set of diagnostics output. The two files required are REF.ALI, which is the average reference waveform, and MULT.ALI, which is REF*(REF-TEST), or the integrand in equation (1). These two were manually sent back to the 7854 where cursors are placed at the $^+/_-\ 2\sigma$ points and an integration performed using the Waveform Calculator AREA function.

3.2 *New Computer*

A PC based on a 80486 processor has been purchased. This has enough storage to hold all datafiles required for a series of vessel measurements, and enough memory to allow acquisition/processing and display programs to run together. The 7854 scope interface has been implemented using the graphical programming system LabVIEW for Windows® [7,8,9] to provide a flexible operator interface, together with a powerful analysis package. At present the front panel provides read-from and send-to-scope options, where both have been written to allow intelligent pickup of file names and scope parameters. The scope settings, e.g. single shot or multiple averaging acquisition, can also be set from the PC. Network access to a data archive has been implemented so e.g. it is possible to check the bellows shield of a new vessel in 1994 against one measured in 1992, without moving from the vessel preparation clean room. An interface program has also been implemented in LabVIEW to convert files into the required format for the program WFORM to run. This is still used, with execution times of <20s rather than the 10 minutes found previously. Two upgrades to the system are already planned: the first will give automatic computer control of the scope cursors, for both the setting of integration limits and the automatic calculation of Z_0 from T.D.R. information; the second will replace WFORM with a LabVIEW package, which will align the waveforms and will calculate and integrate both REF and MULT waveforms referred to above.

4. VESSEL MEASUREMENT SYSTEM IMPROVEMENTS.

A new test rig has been designed to overcome the above problems. A schematic layout is shown in Figure 5.

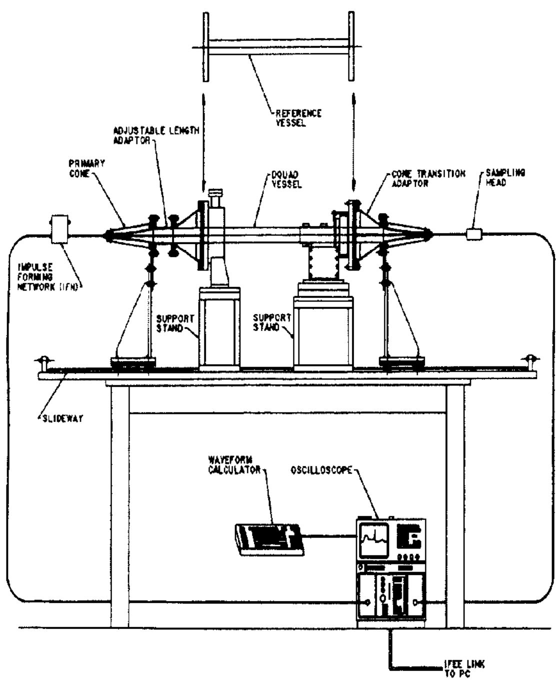

Figure 5. Layout of New Impedance Measurement Rig.

This rig will have one set of master launch cones, the primary cones, made to a high tolerance from copper which will transform the line impedance from 50 to 138Ω (for a centre conductor diameter of 5mm), tapered to give linear rate of increase of impedance with length, which will mate with secondary cones to transform to the specific geometry and impedance of the vessel to be tested. The entire impedance launch system will be mounted on platforms on a sliding rail, allowing a vessel to be hoisted into place (on a rail-mounted plinth), then the cone sections offered up to the vessel flanges, followed by the threading through of the centre rod. An adjustable length section at 138Ω will allow better fitting of the central conductor length to that of the vessel. The centre conductor will be brass for most of its length, to reduce mid-vessel sag which had caused a problem in testing >1m long vessels such as the SRS-2 F-Quadrupole. The rod will be one piece, to remove a major problem with the multi-section rods presently in use, the dropping out of place of an end of a section necessitating a time-consuming cone removal and replacement to re-fit the rod.

Since the loss parameter calculation is based on measuring the difference in signals travelling through a perfect vessel (the reference vessel) and an imperfect one (the vacuum vessel under test), one of the most significant changes to the measurement system will be that the same launch cones will be used for both vessels, so that their effect will cancel out. A correctly matched reference vessel will be swapped with the vessel under test to complete the data set.

Other improvements will include: ultra-thin low dielectric centre rod supports placed at the secondary cone flange, to reduce the ripple seen on T.D.R. plots because of multiple reflection from the localised high dielectric; and the replacement of SMA RF connectors for APC-3.5. Since the fourier components of a 20ps σ pulse extend to >10 Ghz, good constant impedance connectors are a necessity. SMA connectors replaced N-types a few years ago, but they are relatively fragile. Because of the large number of connections needed for one vacuum vessel test (T.D.R. waveforms and up to 10 sets of gaussian pulse waveforms), several SMA connectors and semi-rigid cables have failed during testing. APC-3.5 connectors will mate with SMA, but have better impedance characteristics and are physically more robust.

In conclusion, a set of upgrades to the impedance measurement facility at Daresbury will yield better results for both the SRS and any future light source projects.

5. REFERENCES

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