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A NEW DEBUNCHING CAVITY FOR THE ISIS H⁻ INJECTOR

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Abstract

The energy spread of the ISIS 70MeV H^- injected beam is reduced using an RF debunching cavity. The existing cavity consists of a mild steel vacuum vessel containing a water-cooled copper shell into which Radio Frequency (RF) power is fed. The unit is made up of components designed for the 50MeV Proton Linear Accelerator (PLA) which used to occupy the Rutherford Appleton Laboratory (RAL) site between 1957 and 1969. The component drawings date back to the late 1960s. Due to its age, complexity and a lack of spares, there is a need for a modern solution. This paper documents the development of a new debunching cavity for the ISIS neutron source.

INTRODUCTION

The ISIS H^- Injector consists of an ion source, a 665keV Radio Frequency Quadrupole (RFQ) followed by a four tank Drift Tube Linac (DTL) which accelerates the H^- beam up to an average energy of 70MeV. The pulsed H^- beam (50Hz, 200µs pulse length) is then passed through a High Energy Drift Space (HEDS) before being injected into the 800MeV ISIS Synchrotron. A debunching cavity acts to reduce the energy spread of the beam prior to injection, whilst maintaining the beam's average energy [1].

EXISTING SYSTEM

In the existing unit the RF flows around a water cooled copper shell which sits on rails inside a nickel plated mild steel vacuum vessel. The shell can be seen in Figure 1. It is the shape of this copper shell that determines the debunching cavity performance. The cavity has several auxiliary components; one manual tuner and one automatic tuner to adjust the volume of the internal RF cavity, a water manifold, diagnostic RF loops which feed back the RF signal from inside the vessel, a vacuum port for pump down, and an RF feed to provide power. Table 1 lists the main operating parameters.

Some of the more interesting aspects of the system are described below.

Water Cooling

The RF surfaces inside the debunching cavity consist of a copper cylinder blanked off at either end with a copper end flange. Drift tubes protrude through the end flanges. This internal unit is water cooled, meaning that there are water connections and water circuitry inside the mild steel vacuum vessel. This has leaked in the past causing a loss of vacuum and forcing the shutdown of the ISIS machine for a 48 hour period while repairs were made.

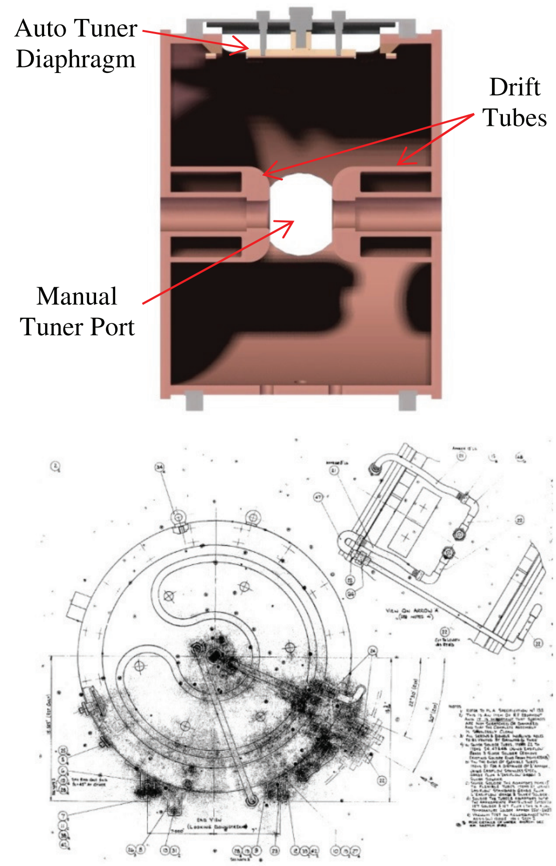

Figure 1: Section through a CAD model of the existing debunching cavity RF shell (top) and engineering drawing showing its cooling channels (bottom).

Table 1: Electromagnetic Properties of the New Debunching Cavity for ISIS [2]

Property	Value	Unit
Resonant frequency	202.5	MHz
On axis average electric field	0.963	MV/m
Transit time factor	0.930	
Effective on axis voltage	0.410	MV
Unloaded Q	36700	
Shunt impedance	28.0	MΩ/m
Peak RF power	13.1	kW
Peak surface electric field	9.70	MV/m

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Tuners

The automatic tuner and the manual tuner are both bespoke units. The manual tuner drives a piston into the copper shell and is used to set the cavity at the approximate operating frequency. The automatic tuner also adjusts the internal volume by moving a flexible copper diaphragm which forms part of the copper shell. In this way the internal volume can be adjusted to compensate for temperature changes, thereby keeping the cavity on tune.

Vacuum Valves

The Debuncher is flanked on either side by two vacuum valves so that it can be isolated in the event of a problem. Their age means that they are at risk of failure. Furthermore, the time the valves have spent in the synchrotron means that they have become activated, making repairs troublesome.

Internal Shape

The current debunching cavity is made up of a combination of components from previous cavities as well as parts designed specifically for this unit. The drift tubes are modified from DTL drift tubes. They are cylindrical in shape and contain internal space for a quadrupole magnet necessary in a DTL but unnecessary for a debunching cavity. The fact that the debunching cavity is constructed in this way means that its internal shape is not as efficient as it could be.

NEW DESIGN

Figure 2 shows a CAD model of the new debunching cavity. The unit has been designed to achieve the same effect on the beam as the existing cavity and therefore contains many of the same components. The main difference is that in the new unit, RF power will flow around a 200μm thick layer of copper deposited on the internal surface of a stainless steel vacuum vessel.

Water Cooling Circuit

The water cooling circuit on the new unit has been designed such that it is completely outside of the vacuum boundary. Any water leaks will therefore not spoil the vacuum. A water manifold splits the inlet flow and sends it to either end of the debunching cavity. At each end, water is supplied to the drift tube and end flange in series before leaving the system.

Tuners

The tuners on the new unit use commercially available linear shift mechanisms (LSMs) to position copper pistons inside the vacuum vessel thereby adjusting the internal volume and consequently the resonant frequency. The manual tuner uses a hand wheel driven LSM with a brake to perform the coarse tuning. An electronic feedback system controls a stepper motor driven LSM which performs the automatic fine tuning.

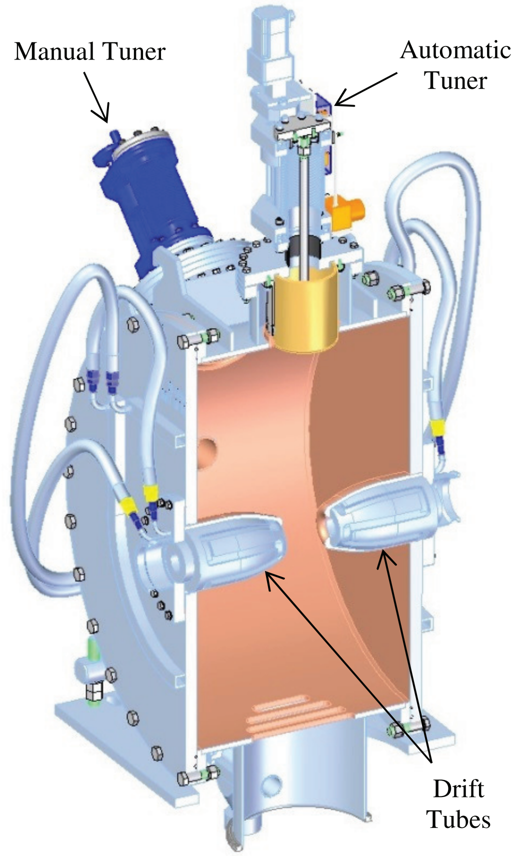

Figure 2: Section through new debunching cavity.

Vacuum Valves

Two new pneumatically actuated VAT all metal gate valves will replace the existing vacuum valves. These are modern units which will be supported by the manufacturer for the foreseeable future.

Internal Shape

The internal geometry of the new unit makes for a much more efficient design. The most significant gains have been made through modifying the shape of the drift tubes. Simulations predict that the new unit will require approximately half of the peak RF power of the existing unit. Comparing figures one and two illustrates the differences in drift tube shape.

ANALYTICAL WORK

Design of Water Cooling Circuit

The new debunching cavity will require less power to run than the existing unit. An investigation was therefore performed to determine which, if any, of its surfaces would require cooling. Table 2 details the heat loads which will be placed on each of the RF surfaces. Hand calculations and ANSYS simulations were performed to determine the temperatures that each component would reach if left uncooled. From this analysis it was decided that at least the end flanges (uncooled temperature of ~47°C) and drift tubes (uncooled temperature of ~603°C)

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would require cooling although it was possible that the cylindrical cavity wall (uncooled temperature of ~40°C) could be left uncooled. The listed values of temperature only consider the items in isolation, and ignore the effects of, for example, heat from the drift tubes being conducted into the cooler end flanges to which they connect [3].

Table 2: Heat Loads on the New Debunching Cavity [1]

Property	Value	Unit
Cavity Wall thermal Power	76.4	W
End Flange Thermal Power	73.6	W
Drift Tube Thermal Power	52.0	W

On this basis a cooling circuit was designed to comply with the existing ISIS temperature controlled water circuit from which the current debunching cavity is supplied. Table 3 lists the parameters of the water circuit and the calculated results for the new debunching cavity.

Table 3: Parameters for Tank Cooling Circuit

Property	Unit	Max Allowable Value	Debunching Cavity Circuit Value
Pressure Drop	bar	3.27	0.75
Flow Rate	litres/min	18	1.9
Delta T	°C	1	0.73

The performance of the designed cooling circuit was simulated in ANSYS. The simulation of the total system demonstrated that the new debunching cavity would operate at reasonable temperatures, as can be seen in Figure 4.

The final configuration of the cooling circuit is shown in Figure 3. Note that the cavity wall is not water cooled.

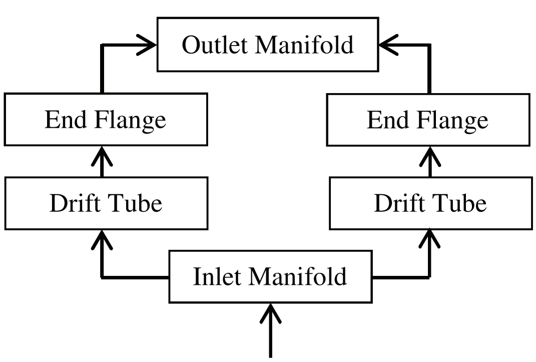

Figure 3: Schematic of cooling system.

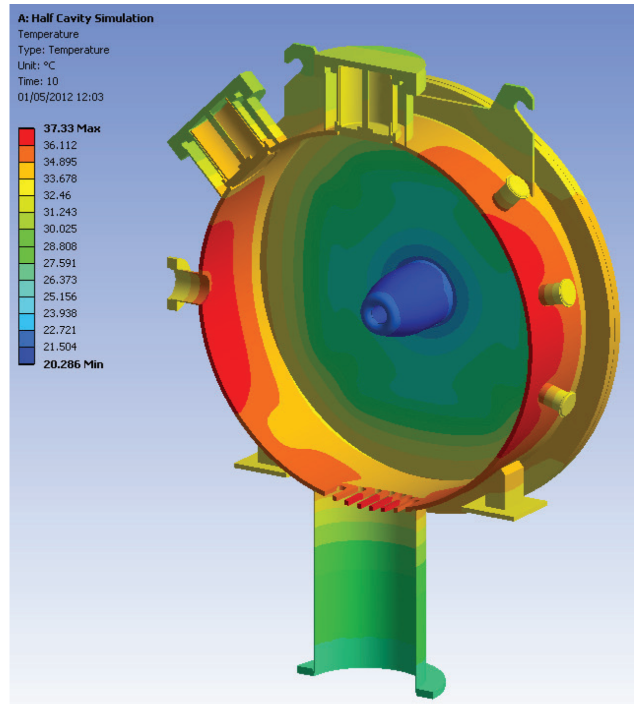

Figure 4: ANSYS simulation of debunching cavity temperature [3].

Sensitivity Analysis

When the new cavity is in operation its temperature will rise. The associated thermal expansion will cause a change in internal volume and therefore a shift in resonant frequency. Similar effects will be produced by the vacuum loads on the system. A sensitivity study was performed to determine whether these changes in internal volume could be counteracted by the debunching cavity's tuners, and therefore whether the desired resonant frequency of 202.5MHz could be maintained. It was calculated that the effects of thermal expansion and vacuum loading would produce a shift in resonant frequency of 0.04 MHz which falls within the total tuning range of the unit of 202.5 +0.580, -0.425MHz [4].

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