REDESIGN OF THE ISIS MAIN MAGNET POWER SUPPLY STORAGE CHOKE

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Abstract

The ISIS facility, based at the Rutherford Appleton Laboratory in the UK, provides intense pulsed neutron and muon beams for condensed matter studies. As part of the facilities upgrade and refurbishment program, the 1MJ storage choke which forms part of the main magnet power supply system, will be replaced with a number of smaller units. The present storage choke, which consists of a split secondary winding transformer, is incorporated into a series-parallel resonant circuit known as the 'White circuit' [1]. This circuit ensures that each magnet receives identical currents, but is not subjected to excessive voltages. Although the storage choke is essentially a transformer, its secondary magnetising inductance is relatively low and a precisely defined value. This paper discusses the design and development of ten smaller units which will eventually replace the present equipment, and the testing of a one fifth scale model, which will be used to prove the technology.

INTRODUCTION

The refurbishment of the main magnet power supply (MMPS), and in particular the storage choke upgrade, is part of an ongoing obsolescence programme at ISIS. Most of the power supply components were manufactured in the 1960's and are reaching the end of their life.

Wherever possible, the upgrades need to be performed with as little disruption as possible to the operation of ISIS. To alter the basic methodology of the power supply system would cause an extended shutdown period as the old systems are removed and the new ones installed and commissioned. It was therefore decided that a duplication of existing equipment, albeit with modern technology, would mean minimum downtime and lessen the technological risk.

It has been proposed [2] that the current choke be split into ten smaller units. This lessens the manufacturing complexity of such a large device and introduces the opportunity to have a spare, should a failure occur.

CURRENT SYSTEM

The current 1MJ storage choke was part of a previous synchrotron experiment, NINA, at the Daresbury Laboratory, UK (fig. 2).

It was incorporated into the current system when ISIS was built as part of the White circuit. The choke consists of ten interleaved primary and secondary windings. Each secondary winding resonates with part of a capacitor bank at precisely the frequency of the synchrotron cycle, 50Hz, in the same way the magnet coil resonates with a further part of the capacitor bank. One of the secondary windings is split at its centre point allowing the insertion of the DC bias power supply and to define the earth potential of the system (fig. 1). The DC power supply and filter components provide a 662A bias level for both the choke and magnet coil.

To ensure that each secondary circuit (and hence, each magnet set it powers) has the same frequency and phase relationship there needs to be good coupling between primary and secondary windings. The primary windings are connected in parallel and form a close coupled circuit with each resonant circuit. This coupling method reduces the leakage inductance and stray magnetic fields.

To make up the AC losses in the system, an alternator power supply is connected to the primary windings. The turns ratio of the primary to secondary windings is 1:4. The rated secondary AC rms voltage is 14.4kV at 1022A. The nominal peak energy stored is 0.99MJ, 310MVA. The choke windings and core weigh 90 tonnes and with the oil tank, the weight is in excess of 120 tonnes.

The choke has been operating for thirty years of continuous service but is a major cause of concern with the reliability of the system. The state of the insulation is unknown and the tank leaks oil which needs to be continually replaced. If the choke were to fail, the ISIS facility would most likely be down for an unknown period of time and repair would be difficult.

PROPOSED SYSTEM

The proposed upgrade replaces the current 1MJ storage choke with 10 off 100KJ, 160mH units. As the replacement chokes will have to be compatible with the existing White circuit, there will be many key features which are historic to the existing system and whose values are therefore fixed.

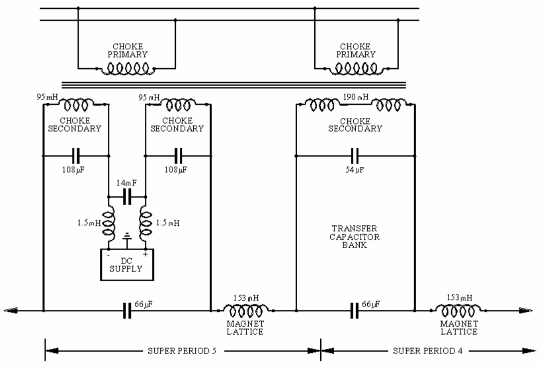

Fig.1. "White Circuit" Power Supply Configuration.

The energy resonating between the capacitor bank and the choke will be stored in an air gap which will in turn, by its dimensions, determine the inductance of the unit.

Studies have revealed that by using multiple air gaps, the stray magnetic fields in the winding region can be reduced and therefore not incur large eddy current losses in the copper conductors. Each air gap will be screened by a winding and so external stray magnetic fields are also kept to a minimum (see fig. 3).

Originally, the chokes were going to be 200mH, but it was deemed appropriate to lower the inductance level to 160mH which would result in reduced core mass and therefore lower cost. The effect of this would be that the capacitance needed in the system would increase and the cost of this would be lower than having the higher inductance value.

SCALE MODELS

In order to facilitate the design of the proposed choke system, three 40mH ‘scale model’ chokes have been ordered. The models will provide as much information as possible about stray fields and losses, magnetic iron saturation levels, conductor cross section and winding arrangements.

In the initial stages of the design process, it was hoped that the models would provide a detailed scaled representation of the magnetic fields present in the larger 160mH chokes. Finite element models were produced of a typical ‘C’ core design with distributed air gap. The initial studies were performed in 2-dimensions, the assumption being that the 3rd dimension is infinite. Losses can then be worked out per unit length. In order to produce a scale model, the 3rd dimension (the length of the core) would be scaled accordingly.

This was acceptable for a rectangular core, but for a cylindrical core design it was almost impossible to simulate using finite element software in 2D. A 3D approach would be needed. The magnetic iron cross section would be reduced to attain an inductance of 40mH, but the magnetic field distribution would almost certainly be different to the 160mH version.

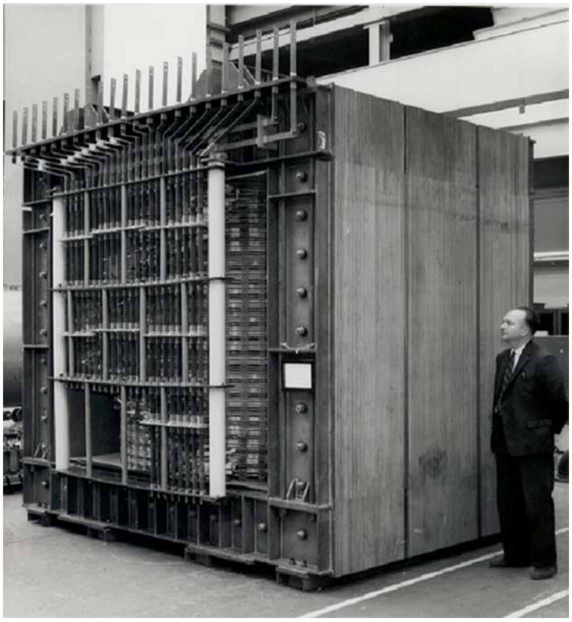

Fig. 2. Existing storage choke (before installation).

The scale models will give invaluable insight into the design of this type of equipment, and will ensure that the correct manufacturer will go on to produce the full size units.

The scale models will be tested on site to see if they meet the specifications laid out at the tender stage. They will also be used, in conjunction with a spare capacitor bank, to set up a small White circuit. It is hoped that this

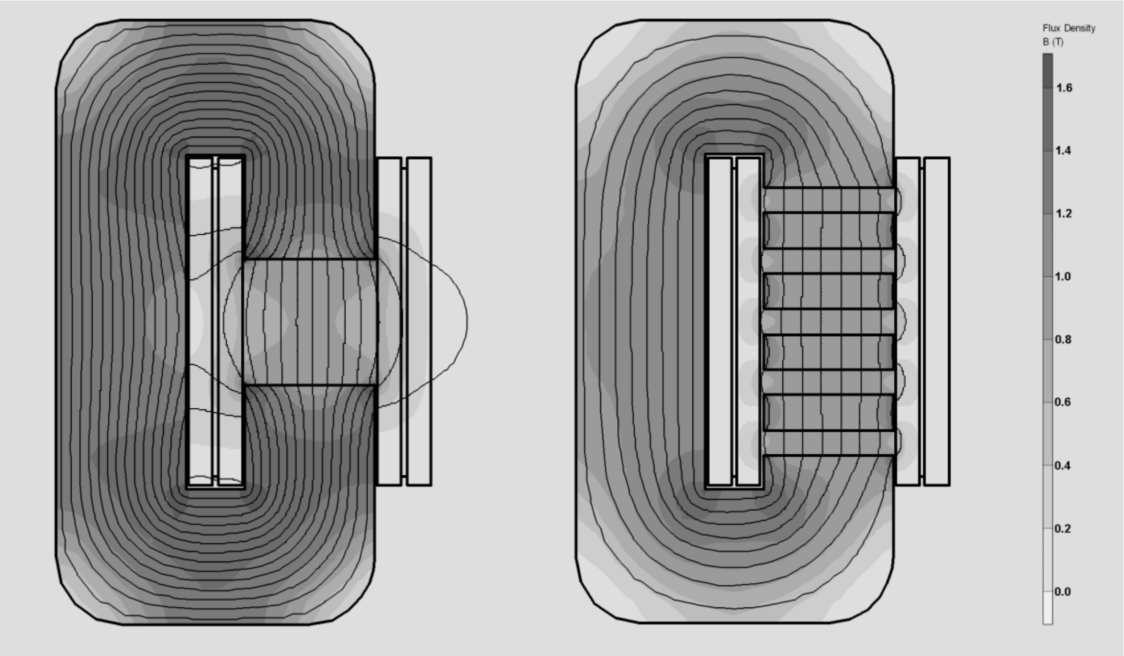

Fig. 3. Magnetic fields resulting from single air gap (left) and multiple air gap (right) ‘C’ core designs.

will give us some insight into how the chokes will interact with each other in the system. The current choke has each secondary winding interleaved with the primary winding which has the effect of producing very good coupling. As the proposed system will have each secondary winding in a separate unit, the design will have to ensure that the new coupling value will approach that of the current system.

TESTING

The model chokes will be tested to ascertain the suitability of each design for the main magnet power supply. Testing will take place in a specially constructed test bay at RAL and will contain a scaled down version of a small White circuit (Fig. 4).

The chokes will be tested in turn applying various voltage and current levels suitable for each test. The chokes that are not on test will provide the ‘load’ for the system.

There will be five technical areas to be considered in the assessment, some of which will be considered more important than others. It is important to test the chokes fairly, which is difficult, as different manufacturers may use different design techniques to fulfil the brief.

Losses will be considered in the system. The model choke on test will be operated at 650A DC through its secondary or main winding. The choke will then be excited by its primary, or auxiliary winding at 50Hz to give a secondary AC current of 250A rms. The value of the AC and DC power will then be subtracted from that supplied to the choke. This will be considered as the total losses for the choke.

Stray magnetic fields are important to minimise. The area in which the ten production chokes will be installed is limited and so the units will need to be placed relatively close together. To avoid stray magnetic fields interfering with the operation of the other units, this value needs to be as small as possible. The choke will be operated at a DC bias current level of 650A. The choke will be excited by its primary winding at 50Hz to give an AC current of 250A rms. The magnetic field will then be measured at three points and the rms of these values calculated.

Imperfect coupling between the primary and secondary windings will cause leakage inductance. The model choke will be operated at a DC bias current of 650A and the primary winding will be short-circuited. The choke will be excited by its secondary winding to give a primary rms current of 100A. The secondary winding voltage levels, currents and power factor will be measured. The test will be repeated with the primary winding open-circuited at a secondary current of 250A rms. The values of secondary and leakage inductance will be obtained, the ratio of which will be considered the leakage inductance coefficient of the choke.

Linearity of the choke will be obtained by operating at a secondary DC bias level of 650A. The primary will be open circuited. The secondary will be excited to give currents of 100A, 150A, 200A and 250A. Primary voltage and secondary voltages, currents and power factor will be measured. The secondary inductances will be obtained and the mean calculated. The maximum deviation from the mean will be considered the linearity coefficient.

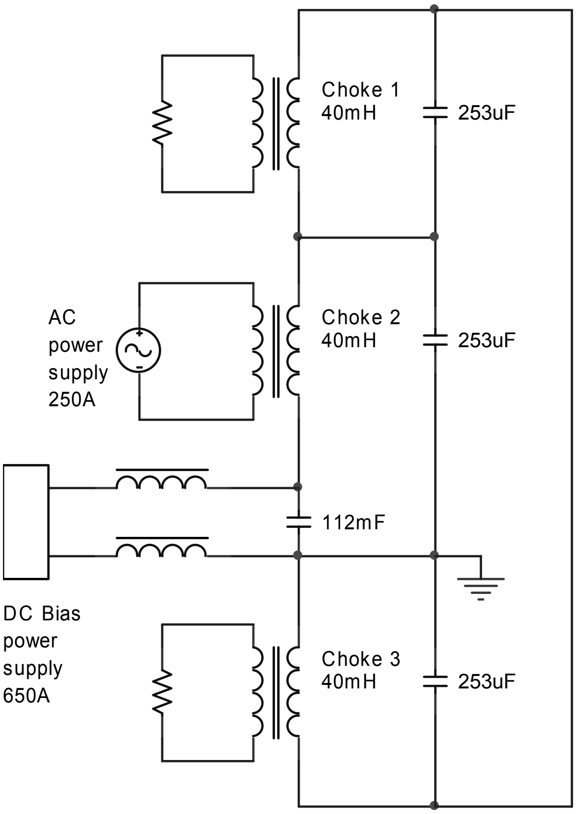

Fig. 4. Model choke test circuit.

Mechanical noise will be considered to assess the vibration effects of the magnetic forces. The choke will operated at a DC bias current of 650A. The choke will be excited by its primary to give a secondary AC current of 283A rms. The noise power in dBA will be measured at three points.

CONCLUSIONS

This paper has outlined the proposed replacement of the current ISIS 1MJ, 2H storage choke. Since the manufacture of a duplicate unit is non-viable, 10 units will be produced in its place, with one prototype constructed prior to this which will eventually become a spare, should a choke fail during operation. The replacement of the choke will have to be made without significant reduction to the availability of the machine. This will be achieved by installation of the new system ‘in parallel’ with the current choke, with a switch over taking place during a shutdown period.

REFERENCES

[1] M. G. White et al., “A 3-BeV High Intensity Proton Synchrotron”, The Princeton-Pennsylvania Accelerator, CERN Symp. 1956 Proc., p 525.

[2] J. W. Gray, W. A. Morris, “Upgrade of the ISIS main magnet power supply”, 7th European Particle Accelerator Conference, 2000, Vienna, p 2202.