Injection Dipole PSU
New Cable Specification

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The Injection Dipole cable will be replaced at the same time as the power supply and bus bar. The following describes the specification for the new cable.

Introduction

The ISIS Injection Dipole power supply will be replaced in 2018/19. At the same time, the opportunity will be taken to replace the magnet cable.

The cable will carry a pulse of up to 15 kA for a maximum of 550 µs + 2×100 µs quarter sinewave rising and falling edges, repeated at 50 Hz.

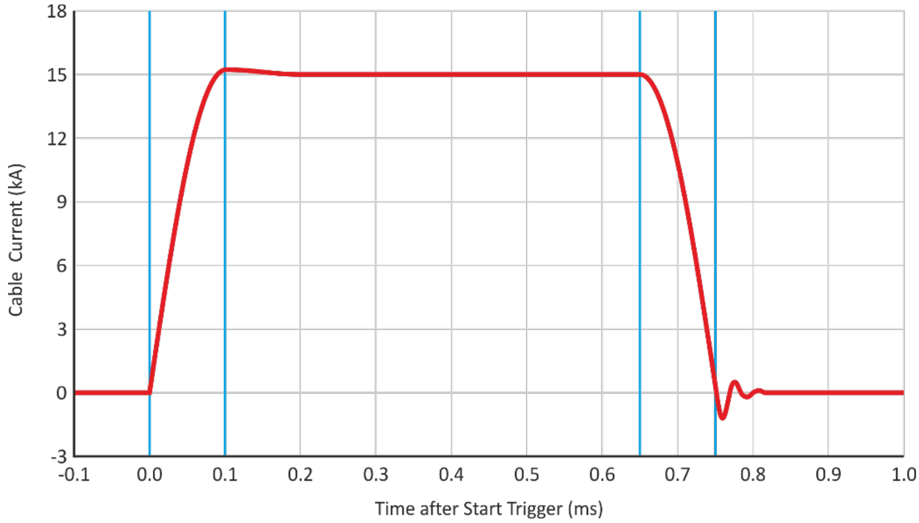

Figure 1. Current waveform

The existing power supply uses 20 cables of a coaxial design, connected in parallel. The cable is terminated on to bus bar at both ends. The load is four magnets connected in series and a parallel matching circuit. The termination at both ends will be changed but the magnets will remain. The magnet characteristics are given as shown in Table 1.

DC Magnet resistance	672 µΩ
AC* Magnet resistance	5300 µΩ
DC Magnet inductance	6.2 µH
AC* Magnet inductance	5.4 µH

Table 1. Magnet characteristics

*AC frequency is that of the pulse rising edge, 2.8 kHz

Requirements

Makeup

The cable will be of a coaxial construction with an additional armour layer. It may be necessary to use a triaxial construction, where the armour layer is also required to be conductive, in order to reduce electromagnetic emissions. In this case, the outer shield may consist of a steel wire armour wrapped around copper foil. STFC will require advice from the cable designer as to whether this is necessary.

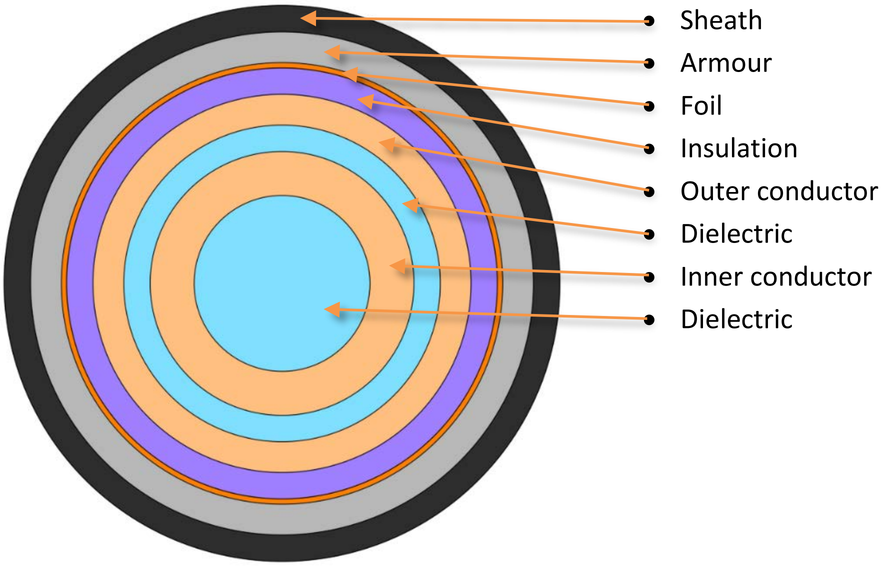

Figure 2. Cable with armour example

It is a priority for the difference between AC and DC resistance to be minimised (maximum ratio to be 1.6), along with overall losses and stored energy. This can be achieved by minimising the skin and proximity effects by keeping the conductor strand size small, insulating each strand and alternating the strand position within the cable.

The skin depth in copper at the rising and falling edge frequency is 1.29 mm (see Electrical section below for more detail). Therefore, the strand size should be less than 2.58 mm (0.1 inch, 10 AWG) in diameter.

To prevent strands sharing current as one large conductor, each strand must be insulated from the next. This can be done effectively by heating the copper during construction, to form an oxidised layer. This layer is of high enough resistance at high frequency to prevent the sharing of current. For more information, please see: “Optimization of Stranded-Wire Windings and Comparison with Litz Wire on the Basis of Cost and Loss.” By Xu Tang and Charles R. Sullivan, published in IEEE Power Electronics Specialists Conference 2004.

Specification

The new cable will be:

Electrical characteristics

- Characteristic impedance at high frequency (>1 MHz) ....8 Ω
- Voltage rating ....4 kV* for 100 µs
- Nominal peak current...15 kA* for 600 µs

Resistance

- Maximum DC resistance...358.8 µΩ.m^{-1}
- Maximum AC* resistance..575.6 µΩ.m^{-1}
- Maximum ratio of AC to DC resistance 1.6

Inductance

- Maximum DC inductance .... 83.78 nH.m^{-1}
- Maximum AC* inductance .... 57.7 nH.m^{-1}

Capacitance

- Maximum capacitance between conductors ....695 pF.m^{-1}
- Maximum capacitance between outer conductor and foil/armour ....1700 pF.m^{-1}

Conductance

- Maximum conductance...0.34 pS.m^{-1}

Physical characteristics

- Maximum overall outer diameter ....35 mm
- Minimum bend radius ....1 m
- Minimum cross section area of each conductor ....70 mm^2
- Minimum outer sheath surface area per metre length .... 75400 mm^2

Temperature

- Expected temperature rise† ....<20°C
- Operating ambient temperature...0°C to 40°C

Life expectancy

- Mean time between failures ....> 30 years

*at approximately 2.8 kHz. See Electrical detail section below.

†assuming installation on two horizontal cable trays with a single layer of touching cable. See Installation detail section below.

Length

A total of 2.4 km of cable is required. The route from power supply to magnet is approximately 80 metres.

The cable will be delivered on 4 drums, with 600 metres on each.

Electrical

The cable will carry a pulse of up to 15 kA for a maximum of 550 µs + 2×100 µs quarter sinewave rising and falling edges. This pulse repeats at 50 Hz.

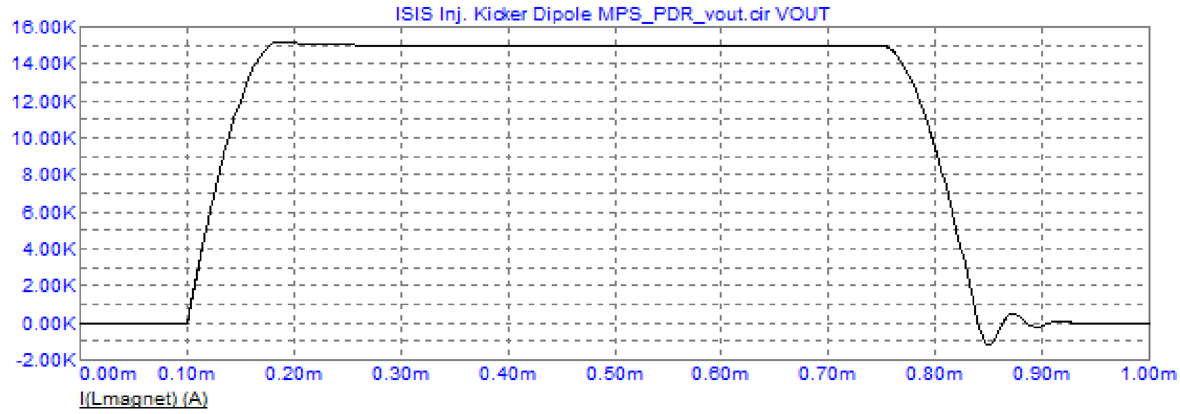

Figure 3. Simulated current waveform

The voltage on the inner conductor will rise quickly (much faster than the quarter sinewave frequency of the current rising edge) to 1600 V, with respect to ground, and decay during the rising edge of the current pulse. The voltage will be maintained at a low voltage during the flat top and falling edge. After the falling edge of the current pulse, the voltage on the inner conductor will spike before returning to zero. The inner conductor voltage waveform is shown in red in Figure 5.

The voltage on the outer conductor will be held at 0V, with respect to ground, until the falling edge of the current pulse when it will rise to -1500 V, drop quickly and, again, oscillate. The outer conductor voltage waveform is shown in blue in Figure 5.

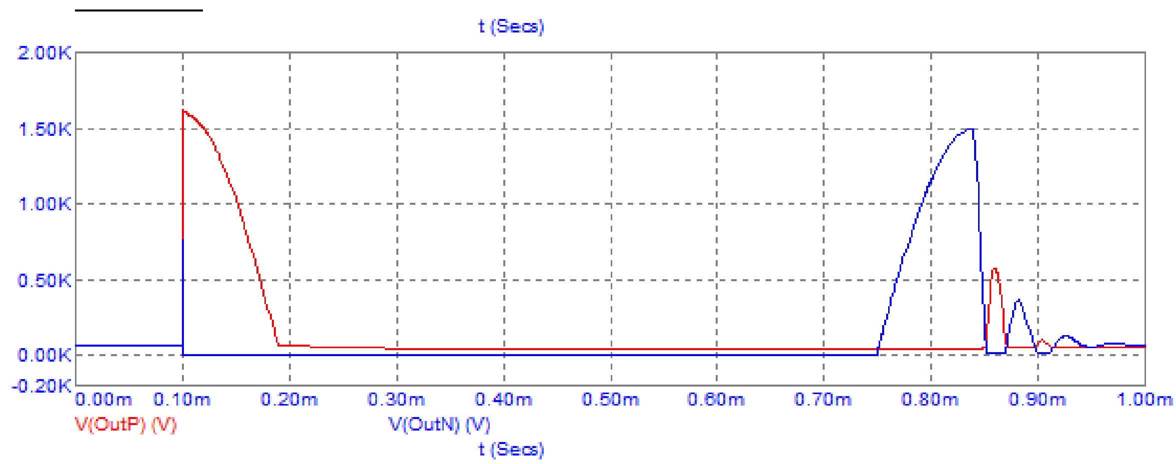

Figure 4. Simulated voltage waveform of inner (red) and outer (blue) conductors

The cable is required to have a voltage rating of 4 kV for a duration of 100 µs. This is more than double nominal peak voltage in order to prevent damage to the cable under fault conditions.

Characteristics of the cable are considered at two frequencies, written above as DC and AC. The AC characteristics are dominant during the rising and falling edges of the pulse. During this period, the skin effect causes the current to flow in only the surface of the conductors. The frequency of the rising and falling edge is assumed to be 2.8 kHz, giving a skin depth of 1.29 mm.

Radiation

The magnet end of the cable will be in an ionising radiation environment. Plastics will degrade at an accelerated rate in this environment, some faster than others. It will be important to consider which materials are used, particularly for the dielectric, insulation and outer sheath. The graph below gives an indication of radiation hardness for some common materials. The better the materials are listed at the top of the table. No material that is not recommended for radiation doses of 1 MGy (10^6 Gray) will be allowed.

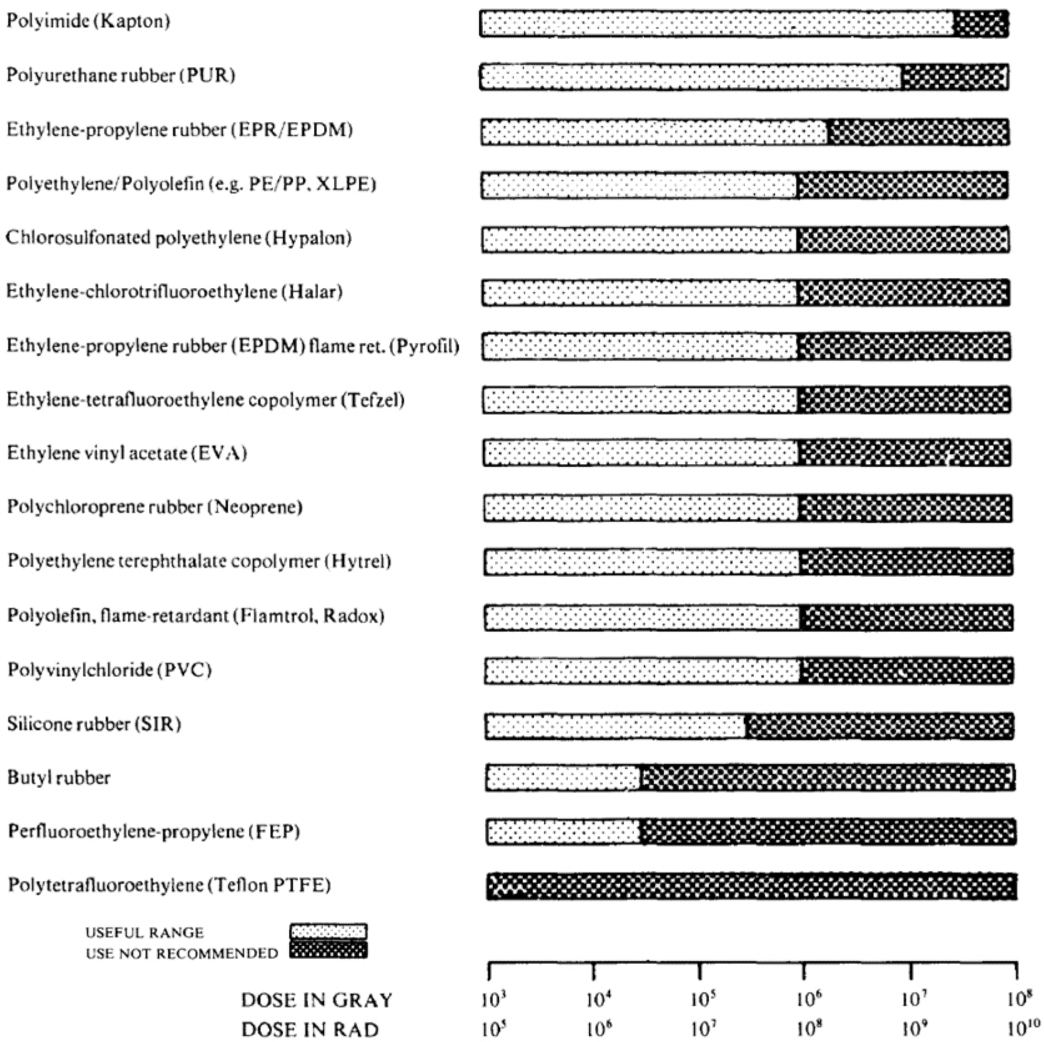

Figure 5. Material radiation damage (https://radiation-damage.web.cern.ch/content/radiation-damage)

Low smoke zero halogen

The outer sheath of the cable is to be made of a material that has low emission of smoke and corrosive gases when affected by fire. PVC is not permitted.

Connectors

We request that the cable supplier recommend a connector or connection method for the cable offered. The cable will be terminated at both ends onto a pair of bus bar. The bus bars will be in close proximity to each other to reduce inductance.

Installation

The cable will be installed in a large tunnel with no forced cooling. Installation will be on two horizontal cable trays, mounted one above the other on the tunnel wall, with sufficient space between them to negate one heating the other. There will be 12 cables on each tray (10 operational plus 2 spare).

Delivery

Delivery of the cable is required by 5th April 2019.