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THE INSULATING STACK FOR THE NSF TANDEM ACCELERATOR

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Summary

The design, procurement, assembly and installation of an insulating stack for a large tandem Van de Graaff accelerator present many problems. These range from calculating the stability of a large structure made from what are not usually considered as structural materials, to economically producing and assembling the many tens of thousands of components involved.

A description of the stack together with some of the manufacturing and assembly problems and how they are overcome are briefly outlined and references are given to further information.

General Description

The 30 MV tandem Van de Graaff under construction at Daresbury Laboratory has a stack 41.24 m high weighing 100 tonnes which consists of eight vertical columns on a 2 m diameter pitch circle tied together at regular intervals by stiff nodular cast iron rings. Each column is made up of insulating legs which can support a high voltage gradient and tubular steel legs at the centre terminal and dead sections within which the voltage is uniform. There are 18 live sections and 3 dead sections above and below the terminal. The live section columns of insulating legs are made from glass discs protected from electrical surges by annular spark gaps formed by stainless steel grading discs. Each live section is 0.86 m long, has an active insulating length of 0.746 m and supports a voltage gradient of 2.23 MV/m at 30 MV.

The terminal and dead sections contain the beam diagnostic, steering, pumping, stripping and control equipment. They are fitted with an electrically smooth outer skin formed by hinged panels which allow access into the dead sections and the crates containing the electronic control equipment and power supplies.

The stack is supported on a stiff space frame truss which sits on brackets attached to the inside wall of the vessel. The truss has been designed to limit the rotation of the pads on which the stack sits to a value which will prevent unacceptably high bending stresses being introduced into the bottom set of insulating legs. Arranging the stack support internally without increasing the overall size of the vessel maximises the external space available for the analysing magnet and associated equipment.

The top of the stack is propped from the vessel to prevent lateral movement by a support designed to allow for the relative vertical movement which occurs between the stack and the vessel due to differential expansion and the inflation of the vessel. In addition the top support houses eight springs which impart an end load on the top of each column, keeping them under compression at all times, so preventing tensile stresses being set up which could damage the glass insulators.

The machine is designed to operate with an intershield fitted to the stack between the dead section positions equivalent to 0.667 of the terminal voltage. The intershield is 16.05 m long and 4.5 m diameter with an electrically smooth skin on the inside and outside formed by stainless steel panels secured to an aluminium frame. The structure weighs 10 tonnes and is of a bolted construction, which, after pre-assembly can be broken down into its component parts which will pass through the manhole openings for assembly onto the stack. To prevent moments being transmitted to the stack the intershield is supported on pins set in the steel support columns of the dead section. To allow for differential longitudinal movement it is guided at the top by rollers bearing on the corresponding dead section columns.

Equipotential hoops 2.3 m diameter made of 48 mm diameter stainless steel tube are fitted to every third grading disc of the insulating legs. These form an electrically smooth surface on the outside of the stack and ensure uniform grading of the voltage within the stack. Grading discs which do not support a hoop are joined electrically by spring loaded tie bars to other discs in the same plane.

Current is drawn from the terminal through a resistor chain extending the length of the stack. The chain is formed by a series of resistors mounted within aluminium die cast trays fixed between an adjacent pair of columns to grading discs of equipotential. The tray method of mounting was chosen after a considerable amount of research and development in order to give the resistors protection from damage by electrical surges.

Design and Manufacture

To meet the very stringent electrical and mechanical requirements necessary to ensure the efficient operation of such a large complex structure, a great deal of attention has been paid to the construction philosophy, the structural analysis and the design, development and manufacture of the many components.

A detailed analysis of the static and dynamic characteristics of the stack and its supports [1] has been carried out using finite element techniques and idealised mathematical models solved using a computer program specially developed for the purpose. To determine their physical properties for use in the analysis extensive tests were carried out on insulating legs and model tie rings [2].

Many tens of thousands of components are required to produce a stack of the size described and a considerable amount of effort has gone into ensuring their economic production and assembly.

The key components in the stack are the insulating legs [3]. The stack contains 288, each one being made by bonding together 31 insulators between a similar number of grading discs. Borosilicate glass was chosen for the insulators after the extensive high voltage testing of many types of glass and ceramic [4]. A tight specification was sought regarding the limiting of seeds, bubbles and inclusions in the glass, as these defects can initiate electrical breakdown mechanisms at such high gradients.

Insulating Discs

With previous accelerators of this type the quantities of insulating discs required have been relatively small and they were produced by accurately lapping the faces of moulded glass discs to flatness and thickness. This method is very inefficient and expensive for large quantities. In addition no manufacturer would guarantee the quality of moulded discs in borosilicate glass,

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particularly with regard to the exclusion of seeds and bubbles. However, borosilicate glass predominantly free from imperfections was available in the form of rolled sheets, enabling the best areas to be used for the insulators. Having the glass in sheet form introduced additional manufacturing problems, i.e. the discs had to be cut out of the sheets and produced with a moulded edge (tests having shown that a disc with a moulded edge does not break down by surface tracking as readily as one with a mechanical polished edge). Because the commercially available production methods were based on lapping techniques a development programme was set up at Daresbury Laboratory to investigate the use of diamond wheels for cutting, and flame polishing to produce an equivalent moulded edge. It soon became clear that the methods were viable and would be very economic. After further development at Daresbury the processes were transferred to a contractor who, under the guidance of Daresbury staff, brought the system into production. The manufacture of an insulator consisted of: (a) trepanning the disc from glass sheet, (b) rough grinding both faces, (c) grinding the edge to a fine finish suitable for flame polishing, (d) flame polishing, (e) annealing, and (f) fine grinding the faces to flatness and thickness. Accurately and securely holding of the discs for machining is a prerequisite for obtaining the required tolerances. The method normally used commercially is to secure them to a metal plate with pitch. Since the pitch interface cannot be controlled to close limits the tolerances on the thickness and parallelism of the disc faces cannot be guaranteed. To overcome the problem a vacuum chuck was designed and developed to ensure the workpiece was securely held on a very accurately machined surface.

A number of additional problems had to be overcome before the system was considered suitable for production. These included the choice of cutting fluids for the optimum performance of the diamond wheels, the removal of glass powder suspended in the cutting fluid, and the choice of grinding wheel form and composition most suitable for each process. When the system was finally developed and in production the cost per unit was approximately one third that of a disc produced by available commercial methods.

Grading Discs

The grading discs are made from stainless steel, a material which has a high resistance to spark erosion. Each disc consists of a plane centre portion with a specially raised and contoured rim on both sides which forms a protective annular spark gap when bonded to either side of an insulator. The form of the spark gap was chosen after a considerable number of tests and computations [5] to give the best possible protection to the insulator against electrical surges.

The production of a large quantity of grading discs of this type from solid blanks is not economic in either material or labour and saving by machining from stampings or castings would only be marginal. The most economic method of production is by joining together two pressings made from stainless steel sheet. Tools were manufactured and developed to produce pressings in large quantities to close limits enabling the spark gaps to be maintained to the required close tolerances. (0.075 mm).

For the best electrical performance it is necessary to have the mating surfaces of the glass insulator and the grading disc flat to close tolerances. This is to ensure an optimum glue line without voids.

After using thermo plastic adhesive to join the pressing it was decided a flatter, more homogeneous and stronger grading disc could be made by vacuum brazing.

To concentrically locate a pair of pressings with respect to each other a technique was developed of spot welding them together in a fixture after applying brazing powder to their mating faces. When the assembly is removed from the fixture it is stacked with others between quartz discs in a vacuum furnance. With a weight of approximately 10 kg on top of the stack it is put through a brazing cycle where the very accurately ground faces of the quartz are reproduced, bringing the grading discs well within the 0.05 mm flatness tolerance required for a good glue line.

Bonding of Components into Legs

Various methods and techniques of bonding glass to metal were investigated before deciding that for the best results the bond must be made with a hot cure preplaced structural adhesive film. This method gives a high degree of control on the amount and distribution of adhesive in the joints. In particular it ensures a uniform fillet of adhesive at the interface of the grading disc and the insulator arris, the size and shape of this fillet being of the utmost importance for good electrical performance.

A special jig was designed and developed into which the grading discs, insulators and pre-cut adhesive film can be accurately stacked and held in place while being put through a curing cycle. The grading discs are abraded by grit blasting over their bonding faces with silica. Both grading discs and insulators are put through a cleaning procedure and placed in the jig for bonding immediately after drying. Integral heaters are situated on the jig close to the assembled components and the whole is loaded into a chamber which is sealed and in turn evacuated to remove air from the joints and at a later stage in the process as heat is applied, charged with nitrogen to suppress any bubbles which tend to form in the adheive fillet. During the latter stage of the bonding process when the adhesive is molten, an air opeated piston puts an end load on the stack of components to ensure intimate contact between the interfaces and the formation of a uniform fillet of the correct size.

Assembly of the Stack

The stack is preassembled and fitted out in modules consisting of various combinations of live and dead sections. Each module is put together in a fixture which holds the tie rings in the correct relation to one another while the legs are fitted. Securing the insulating legs to the tie rings without introducing unacceptably high tensile stresses in the glass is extremely difficult, particularly when dealing with very large stiff components which have been machined to commercial tolerances. To take up the discrete variations between the tie rings at each leg station a number of schemes involving make up pieces and screw jacks were investigated. These were rejected beause they would not give end fixings stiff enough to ensure the static and dynamic integrity of the completed stack. After a considerable amount of development a special end fixing was evolved which allows the insulating legs to be fixed without introducing stresses into the glass.

The design consists of a composite flange (fig.1) made up of an auxiliary flange cold bonded and welded to each end of the stack leg, which fits into a recess in the main flange. The auxiliary flange seals in an 'O' ring in the wall of the recess in the main flange. The thickness of the top main flange is machined to suit the previously measured distance between the tie

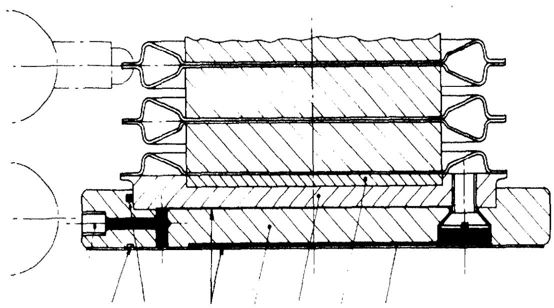

Fig.1 Diagram of end flange arrangement:-
(a) Vacuum port.
(b) Silicone rubber seal injected as a liquid after screws in main flange have been torqued up. Allowed to solidify before drawing a vacuum.
(c) "O" ring, sealing auxiliary flange to main flange.
(d) Epoxy resin, drawn into void under vacuum after screws fixing main flange to bulkhead ring have been torqued up.
(e) Main flange.
(f) Auxiliary end flange, cold bonded to nilo disc and edge welded to grading disc pressing.
(g) Nilo disc hot bonded during leg manufacture;
(h) Sealing shim between bulkhead ring and flange.

rings so as to leave a gap between the faces of the main and auxiliary flanges when the leg assembly has been fitted in place and the flanges bolted in position. The void formed by the gap is evacuated with a roughing pump through a port in the side of the flange. Previously prepared and outgassed epoxy resin is then drawn in through a diametrically opposite port to fill the void and make up for any differences between the tie rings in distance or parallelism without introducing additional tensile stresses. Initial tests indicated that the resins with good flow characteristics which would readily fill the void had relatively poor tensile strength at the flange to resin interface. To strengthen the joint countersunk screws were introduced between the main and auxiliary flanges. The screws are fitted but not fully tightened down before the leg is put into position. This ensures no additional stresses are introduced into the glass insulators when the main flanges are bolted to the tie rings. The fixing is completed when the screws are encapsulated by the resin filling the void between the main and auxiliary flanges.

After the tie rings and legs have been assembled the module is removed from the building jig, the dead sections fitted out, and the equipotential hoops, tie bars resistor chain and other equipment fitted. Prior to assembly in the vessel the module is thoroughly inspected and a comprehensive commissioning programme is undertaken on the systems within the dead section.

Assembly in the Vessel

The stack consists of ten such modules plus the centre terminal. Each one is lowered in turn into the vessel through the top opening onto an adjusting fixture which allows the module to be put in its correct position in relation to the vertical centre line and the module below it. With the correct distance set between the top tie ring of the module in the vessel and the bottom ring of the one being installed, insulating legs are fitted between the two modules in the same manner (by machining end flanges etc. and resin bonding) as described for assembling the modules themselves. With the bonding of the legs complete the adjusting fixture is removed and re-established on the top of the stack ready to receive the next module. The newly installed legs are then fitted with resistors, tie bars and equipotential hoops.

The centre line of the vessel is maintained between an optical instrument point on the stack support truss and a target set in a beam across the top of the vessel. The beam is designed so that it can be rolled to one side allowing the module to be lowered into the vessel using the service crane. Specially designed lifting beams are used so as not to induce tensile stresses into the glass insulators. When the survey beam is put back onto the centre of the vessel it locates on seatings which re-establish the survey target onto the centre line of the vessel.

The stack modules are assembled in the vessel from a temporary annular platform suspended on three wire ropes attached to hydraulically operated pull lifts which can be used to raise the platform as installation proceeds. During construction the stack is propped from the vessel to prevent accidental tensile stresses being induced in the glass insulators. The props are attached to the stack just below the temporary annular platform and are repositioned each time the platform is raised. Access to the temporary platform is gained via the permanent annular maintenance platform which can operate from the base of the stack to within about 3 m of the temporary platform. The temporary platform is of bolted construction so that it can be removed from the vessel in sections through the access manhole.

With the stack complete, the top support in position and the charging system installed, the vessel will be closed and high voltage tests carried out to determine the characteristics of the stack without a tube or intershield. The intershield will then be installed and the tests repeated before finally commissioning with the accelerator tube.

All the stack modules have been built and are in various stages of being fitted out and commissioned. Several completed sections have already been installed in the vessel using the assembly and installation methods described. The operations have proved to be straight forward and ideally suited for such a large machine.

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