The ATLAS experiment at the LHC
The ATLAS endcap signal feedthroughs
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As described in detail in the 1996 Annual Report, ATLAS is building a multi-purpose *pp* detector which is designed to exploit the full discovery potential of the Large Hadron Collider (LHC) at CERN. The TRIUMF group is responsible for the engineering of the hadronic endcap calorimeter (HEC), and contributes to the production of high density cryogenic signal feedthroughs for both endcap cryostats. The feedthroughs are critical to the success of ATLAS. They are being built and tested at the University of Victoria by TRIUMF and Victoria staff. The endcap signal feedthroughs are currently scheduled to be installed on the two endcap cryostats during two periods starting approximately March 2002 and October 2002. At the end of 2001, there was approximately 1.5 months left to the completion of this 7 year project. As this is the first time the endcap signal feedthrough project is covered in significant details in a TRIUMF annual report, the most important aspects of the project are reviewed.

Responsibilities, management and reviews

The ATLAS collaboration has determined that some components of the detector can be regarded as contributions in kind to the Common Fund; these are known as Common Fund Projects. The endcap signal feedthroughs are part of the Canadian group contribution to the Common Fund. The Canadian group is responsible for the assembly, testing, and commissioning of the ATLAS endcap signal feedthroughs, as well as participation in their installation on the cryostats. The design of the feedthrough was made in collaboration with the Brookhaven National Laboratory (BNL), which is responsible for the production of the barrel cryostat signal feedthroughs.

A Canadian involvement in the endcap signal feedthroughs was already proposed in 1995. From the $12.2M Major Installation Grant awarded to ATLAS in the 1997-98 competition, a total of $4.28M is earmarked for the endcap signal feedthrough project. Considerable effort has been spent developing the management tools needed for a successful completion of the project. Documents describing in detail the feedthrough design, the assembly procedures, the test procedures, the procurement plan, the quality assurance plan and the material traceability are available. The administrative structure needed for duty exemption for goods for re-export has been setup in Victoria.

ATLAS reviews of the feedthrough project were held in BNL on 12-13 June 1997, and in CERN on 13-15 October 1997, and 2 October 1998. The feedthrough Production Readiness Review (PRR) took place at CERN on 29 January 1999, where the green light was given for the procurement of the glass technology pin carriers. Status reports were presented at three NSERC ATLAS Reviews (TRIUMF, 9 January 2000, 19 October 2000 and 14 December 2001).

Overview of the project

The ATLAS liquid argon calorimetry is composed of a barrel section and of two endcap sections. Each endcap cryostat contains an electromagnetic calorimeter, two wheels of one HEC, and a forward calorimeter. The calorimeter signal and calibration lines are routed to the outside of each endcap cryostat via 25 feedthrough assemblies arranged approximately equally spaced in azimuth. The low voltage needed to operate the endcap hadronic calorimeter preamplifiers, which are located in the cold, are also supplied via the signal feedthroughs as well as various monitoring lines.

The specifications that drove the technical design of the feedthrough assembly are quite complex. They involve geometrical and space constraints in the cryostat design, physical limitations on the space which is allocated to the feedthroughs, signal transmission quality, vacuum integrity, heat loss considerations, access possibilities, installation, reliability and cost issues. The design is based on gold plated conductive pins insulated and sealed by glass inserts in a stainless steel carrier. The carriers are then welded into the cold and ambient (temperature) flanges. A total of 1920 signal and calibration lines per feedthrough assembly is required in the chosen design. The ambient and cold flanges are connected by a bellows to isolate the feedthrough vacuum from the cryostat inter-vessel vacuum. The cold flange is attached to a transition piece, known as a funnel, which is welded to the cryostat via a bimetallic joint. The electrical signals are brought from the calorimeter to the cold flange by coaxial kapton cables; these are called pigtail cables. Cables located in the vacuum between the cold and the ambient flange, i.e. inside the bellows, carry the signals through the cryostat wall; these are called vacuum cables. For each endcap, four feedthrough assemblies also carry the low voltage for the HEC preamplifiers. Fig. 1 shows an overview drawing of one endcap signal feedthrough.

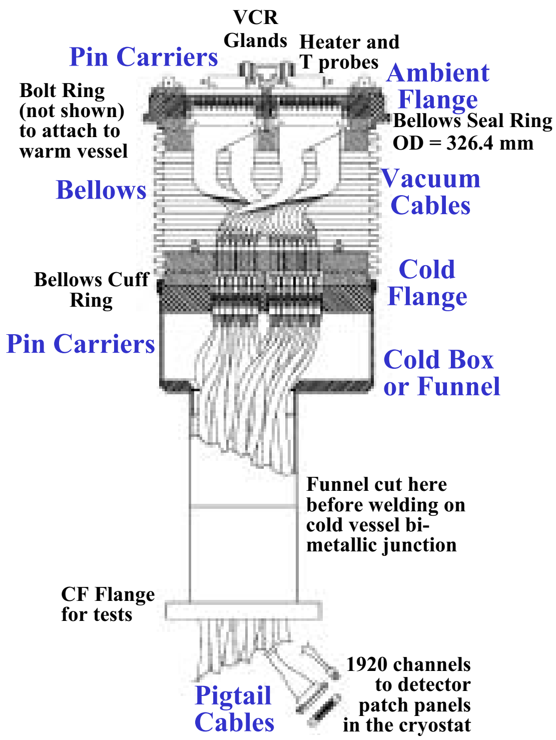

Fig. 1. Overview drawing of one endcap signal feedthrough, identifying its most important components.

Project setup

The project setup comprises the hardware and software required for the production of the feedthrough assemblies. The most important items are the leak test station, the electric test station, and the assembly jigs.

Leak test station

The selected glass technology for the signal feedthrough is mature and has shown good results in applications that require high reliability under extreme temperature and pressure conditions. Still, the application considered here is pushing technology to its limits in order to reach the required density. The failure rate that we can tolerate is essentially zero over 20 years of operation. Since access to the various feedthrough assembly parts will be limited, a detailed and comprehensive testing procedure is vital.

Following the experience acquired in BNL, we have designed and assembled a leak test station that allows warm and cold leak tests to be performed in a controlled way. A precision of 1×10^{-9} atm.cc/s is required and has been achieved. The station is based on a helium leak checker, a residual gas analyser and various pressure and temperature probes that service a warm test station for feedthrough assembly components, and a cold test station for full assemblies. Measurements are read by a PC based LabView DAQ system developed in Victoria. This test station is fully operational.

Electric test station

The feedthrough cables are used to carry analog signals from the cryostats to the outside world, as well as calibration signals into the cryostats. Because of the fast shaping, the signal integrity is a major concern. The grounding and shielding must be of good quality to avoid signal deterioration.

We have developed the electric test station needed to certify the electrical integrity of the signal feedthroughs. This station provides automated measurements of cable resistance, impedance and crosstalk. It uses, among other components, a network analyzer for detailed transient tests, a purpose built channel scanner developed in Orsay and assembled in UBC, and a purpose built channel multiplexer developed at UBC. Measurements are read by a PC based LabView DAQ system developed in Victoria. The instrumentation for testing the low voltage distribution for the HEC feedthrough units has also been developed. This test station is fully operational.

Assembly jigs

Each feedthrough assembly is too heavy to be handled manually. Assembly jigs and related hoists have been developed and built to allow the various phases of the assembly to be performed. In particular, the proper relative orientation of the flanges is ensured by the jigs' design.

Prototyping

Since 1997, our group has produced a full scale model, and purchased or produced prototypes of the various components of a feedthrough assembly. These were vital to the finalisation of the design, the assembly procedures, including the welds, and the choice of suppliers. We have then used prototype parts to construct a feedthrough assembly with a dismountable flange-bellows interface; this prototype, which can easily be reconfigured, has been extensively used for the study of convective thermal loss and the study of leak and electric test procedures. We have also constructed a mechanical prototype to allow the cryostat team to perform various installation tests.

Final design

Contributions to the design of feedthrough assembly components through finite element analyses (FEA) were initiated early in 1996. These analyses, performed by Terry Hodges (TRIUMF), include detailed FEA of the mechanical stresses and deformation for the cold and ambient flanges, equipped with pin carriers, for various design options. Further mechanical stress analyses were performed for the funnel and the bi-metallic joint. These led to design guidelines suitable for both the barrel and endcap feedthrough assemblies. FEA studies of the flange temperature validate the plan to heat the ambient flange via resistors, and prescribe a maximum cooling rate for a safe cold testing of the equipped flanges. A detailed design of the ambient flange heater plate system has been finalized in 2000.

Procurement of components

Vacuum cables

The development of signal vacuum cables in Canada was successfully completed in 1998. Prototype assemblies have been designed and constructed in Canada in collaboration with CRPP and STC. These cable assemblies have been sent for tests to the BNL and LAL/Orsay laboratories. One cable has been irradiated in Grenoble in July 1998 and successfully inspected and tested in Victoria. The performance of these prototypes was very encouraging. A series pre-production of 100 cables was launched at STC late in 1998, and received spring 1999. These cables were extensively tested and found to perform as required. Meanwhile the BNL team has chosen FCI-BERG as the supplier of the barrel feedthrough vacuum cables. Following a Request For Quote sent to both FCI-BERG and STC for the endcap feedthrough signal vacuum cables, our group also opted for FCI-BERG as suppliers. We have now received all 1750 vacuum cables.

Special vacuum cables have been developed for the distribution of the HEC low voltage. Detailed tests with a complete low voltage HEC chain has been performed in Victoria in October 1999. We have ordered (Axon) and received all 40 HEC low voltage vacuum cables.

Pigtail cables

The development of the pigtail cables was part of a larger effort to develop signal and calibration cables for the whole of the LAr readout chain. The pigtail cables for the endcap signal feedthrough are also part of the Canadian common fund contribution. They are purchased through Orsay, along with the other ATLAS LAr cables, from Axon. A Memorandum of Understanding for the procurement of the endcap pigtail cables has been signed by Orsay and ATLAS-Canada. A detailed procurement schedule has been developed, and reception of pigtails in Victoria is now (end 2001) 74% complete. Reception is expected to be completed early in 2002.

Pin carriers

Extensive and detailed tests comparing the ceramic and glass pin carrier technologies were made in 1997 and 1998. Both technologies were found suitable for our project. A glass technology pin carrier was welded to a test flange in Canada and subject to a burst test in CERN. It was found not to be affected by a pressure of up to 250 bar. The green light was given at the PRR to purchase glass technology pin carriers made of low inclusion 304L stainless steel. The order was placed in June 1999. Procurement problems with the low inclusion stainless steel caused approximately six month delays. Further delays occured when the procured steel showed to be unsuitable for hermetic seal use. After extensive studies and tests, coordinated by Tom Muller (BNL) and the manufacturer, a source of suitable stainless steel was found. Pin carrier production resumed in February 2001. We have now (end 2001) received 77% of the required pin carriers. Reception is expected to be completed early in 2002.

Other components

Other components (bellows, flanges, funnels, VCR T-glands and heater plate parts) are all in stock.

Assembly and installation

A total of 50 feedthrough assemblies plus 5 spares must be produced (see Fig. 2). From the experience gained with the prototype construction and tests and with the production of the first assemblies, a detailed assembly procedure, quality plan and quality assurance plan have been developed and refined. These include the description of the testing of components from their arrival in Victoria through the completion of feedthrough units. Complete material traceability is ensured through the use of detailed traveller sheets.

Fig. 2. Vacuum cables being installed on a feedthrough by Paul Birney (TRIUMF) at the University of Victoria.

The funnel and cold flange of each feedthrough assembly are part of the cryostat pressure vessel. An officially licensed company is doing the welding and extensive testing to conform to accepted welding code.

Special test sections of a feedthrough assembly have been made for TIS (CERN Safety Group) tests. Final TIS approval of our welding plan has been obtained.

The shipment of feedthrough assemblies to CERN is done by air freight. Shipping crate construction follows the feedthrough assembly production. Upon arrival at CERN, each feedthrough assembly is subjected to an ambient temperature leak test and a basic electrical test. We are responsible for these tests. The required testing equipment was commissionned at CERN in October 2001, when the first feedthrough assemblies arrived at CERN.

The installation of the feedthrough assemblies on the cryostat is a delicate and complex operation. Although the feedthrough installation is not a Canadian responsibility, our group is expected to actively assist during the operation. In particular, given the softness of the pins, members of our team will manually connect the so-called warm cables that join the outside of the ambient flange to the electronics crate baseplane. Each feedthrough assembly, once welded on the cryostat, must also be electrically tested. Furthermore, we must assist during the leak testing of the cryostat.

Project schedule

The current ATLAS schedule indicates that the endcap cryostats will be ready for feedthrough integration approximately in March 2002 and October 2002. The endcap signal feedthrough project is on track with the ATLAS schedule. As of the end of 2001, 23 feedthrough assemblies have been produced and tested, and 21 are at CERN. An average production rate of 3 assemblies per month, including tests, is expected (a peak production rate of 3 assemblies in 22 days was achieved). It is expected that Canada's involvement in the feedthrough installation will end during 2003 with the connection of the warm cables to the ambient flange.