Mechanical design of cryogenic vacuum feedthroughs for XFEL button BPM's

D. Lipka, Silke Vilcins (DESY Hamburg, Germany)

Abstract

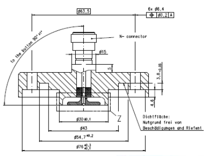
The European XFEL is a 4th generation synchrotron radiation source, currently under construction in Hamburg. Based on different Free-Electron Laser and spontaneous sources and driven by a superconducting accelerator, it will be able to provide several user stations with photons simultaneously.
Due to the superconducting technology in the accelerators modules many components have to operate at liquid helium temperature.
This poster will concentrate on high frequency ultra high vacuum feedthrough used for the beam position monitors of the cryogenic accelerator modules. Main emphasis will be put on the design of these feedthroughs, their material composition and the production process. The capability to be used under these very special conditions was investigated with FEM simulations, as well as with a test procedure. The results of these simulations will be presented; the tests and their results will be explained in detail.

Serial production

The serial production described the steps of final changes and fabrication.

Steps of mass fabrication

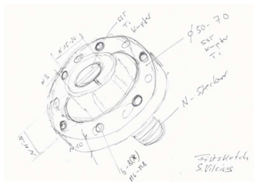
- Tolerances simulation related to real production drawings of suppliers
- Last mechanical design changes if necessary
- New call for price to qualified vendor
- Placing serial production
- "Start up" meeting at plant of vendor
- Communication by "jour fix" and milestones
- Quality check of delivery parts like cleanness, visual inspection, RF and mechanical properties
- Cryogenic test (3 cycles, mass production procedure)
- Preparation to assembly to BPM bodies
- Finalizing quality documents and procedures
- Last vacuum leak check and mass spectrum analysis together with quadruple unit



Introduction and Goal

In particle accelerators like European XFEL (E-XFEL) many feedthroughs are used to monitor the electromagnetic field to determine and verify the actual beam position. At the European XFEL the Beam Position Monitors (BPM's) operate under two different ambient conditions, one under normal room temperature and the other one in a cryogenic environment, at ~4K. The cold button BPMs are installed close to the superconducting accelerator structures. Therefore they have to fulfil strict ultra-high vacuum and particle cleanliness requirements.
Many companies offer vacuum feedthroughs. Here the focus is on feedthroughs suitable for RF applications.

The goal is to develop custom designed feedthroughs with well defined RF properties for accelerator applications at low temperatures and minimum particle emission.



R&D Design properties

Electronic properties:

Impedance: 50 Ω
Highest operating frequency: 2,5 GHz
Bunch Charge: from 0.1 to 1 nC @ 10 Hz
max: 1 nC @ 30 Hz
Spark over voltage: high
Glass to sealing metal: low ε_R
Button diameter: 10-20 mm
Return loss <- 10 dB

Mechanical properties:

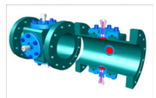
Operating temperature: 4K
Temperature range: 330K – 4K
Vacuum tightness: $1{*}10^{-10}$ mbar l/s under 4K
Purity: Cleanroom Class 5 and better
All materials: permeability < 1,02, non magnetic
UHV sealing: full metal gasket
Servicing: removable no welding
Reliability: very high
Isolation to metal: matched to RF properties and joined by welding, vacuum firing or brazed in an vacuum oven under pressure and high temperatures
Beam pipe diameter: 78 mm

Prototyping

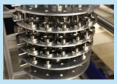
The prototyping described only the work on the mechanical par of the feedthrough.

Steps of project evaluation

- Selecting of materials shell, pin, ceramic, conductor
- First 3 D mechanical design
- Hand over for a first RF simulation
- Change of mechanical design based on simulation results (loop)
- Final design and work on technical drawings
- FEM analysis under cryogenic conditions
- Describe of specification and delivery item
- Start of market analysis and open call for tender
- Selection of vendors and make a quality audit
- Start prototyping with two or three vendors
- Attend the vendors for pre-production
- Quality check of delivery parts like cleanness, visual inspection, RF and mechanical properties
- Cryogenic test under vacuum in cryostat (10 cycles warm/cold from 330 K to 4 K)
- Mount to real bodies and tested with beam (scope or with electronics)
- Analyzing and reporting of results

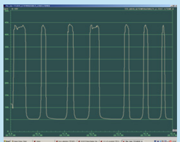


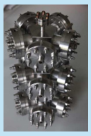
Test procedures and analysis



Mass production

Cryogenic tests cycles

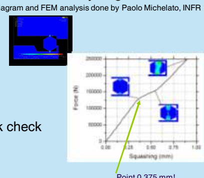




Prototypes incl. Leak check

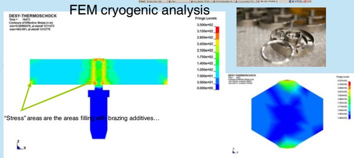
FEM Analysis gasket

The diagram and FEM analysis done by Paolo Michelato, INFR



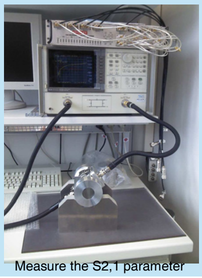
Point 0.375 mm!

FEM cryogenic analysis



Assembly tests

Assembly test of feedthrough to body with the calculated tightening torque in order to check one of the critical tolerances (deepness of the button into the body)



Measure the S2,1 parameter

Project Management efforts and competences

A new R&D projects needs a adaptive project management of required scope volume. In principal the time for design, prototyping and realization of new technical equipment for new accelerator technologies are normally very short.

Steps of project management competences

- Creating a project map with project phases and milestones
- Write down the "target" properties and distinguish between "results" and "process" targets
- Create a phase plan with "time" and "effort"
- Create a risk plan and complete it during the project process also a stakeholder overview
- After "start up" meeting bring the team together and make the project structure plan (PSP), this will be the "plan of plans", detailed in working steps, process steps, time schedule
- Planning of working resources and coast estimation
- Descriptions of the scope, technical documents, procurement papers, claim and change management and take care on the quality management

Results

The serial production of 320 parts were produced in 14 months. This feedthrough was a 100% costumer designed product with hand in hand work to commercial feedthrough supplier.

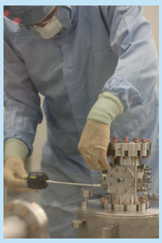
Technical:

- RF simulation showed all of the mechanical properties, assembly tolerances and best material compositions
- FEM cryogenic simulation showed less material stress between isolator washes, inner pin and shell material
- A principle mechanical FEM analyze and practical assembly test formed the procedure and tightening torque for series assembling in classroom ISO class 4
- All parts, prototypes as well, passed the cryogenic test, mechanical check, RF measurements (see picture above) and leak tests, also the particle check after cleaning
- Particle reduced cleaning of items goes fine
- Good UHV conditions, detected by mass spectrum analyze
- One RF property (S1,1 parameter) was checked by a scope, using a special jig and after the feedthroughs were paired twice

Organization:

- Realization of this project with project management aspect gives you more reliability to budget, process, time schedule, **change management and quality controls**
- Knowledge of internal/external procurement processes, project management skills and supplier assessments are advantageous

- Remark: A few parts was shipped back after visual check due to fingerprints, rests of mechanical fabrications process or not cleaned like required (abrasive material from glass blasting)
- Three parts had a misaligned copper button (failed during brazing)



Conclusions and Outlook

- Mechanical tolerances fulfilled RF simulations results "Knob" material defined of copper, due to wake loss simulation
- 40 prototypes passed all tests, incl. cryo cycles (titanium and sst flange material)
- And 320 serial items passed just as well all tests
- FEM analyse and practical tests defined the flange assembly process, forces, friction and tightening torques to guaranty the 0.1 mm accuracy
- Due to assembling test a very good correlation between FEM analyse and practical test to squeezed the diamond aluminium gasket to 0.3 mm
- Ti6 Al 4V stud-bolts and sst nuts (A4 8.8) are a suitable combination
- Brazing technology of titanium to Al_2O_3 provided sufficient stability for cryogenic applications
- Suitable for application and cleaning in class 5 and 4 cleanrooms
- Good UHV performance
- Non magnetic and robust design with an N-connector for cabling

It took 4 years to develop the cryogenic Feedthroughs for E-XFEL from the idea to the last shipment, and the final quality checks. Special attention has to be given to the feedthroughs which need to be produced with high precision and high quality in parallel or even before the mechanical design and electronic readout concept.

Outlook

Based on the experience with the feedthrough for the cryogenic environment, a second project was started to develop and produce also a custom made feedthrough, especially suited to the requirements of linac driven facilities like E-XFEL. These production of feedthroughs went to glass to metal sealing technology in microprocessor-controlled furnaces. This technology brings more than one advantage, because these glass-ceramics have a better relative permittivity then oxide-ceramics. They have very low porosity, low or negative thermal expansion coefficients, low dielectric loss, high mechanical strength, very high thermal-shock resistance and high abrasion resistance to chemical substrates.

Customer designed feedthroughs with very low voltage standing-wave ration losses and with special mechanical characteristics are possible.