ISBN: 978-3-95450-241-7 ISSN: 2673-5350 doi:10.18429/JACoW-IBIC2022-MOP12

PRODUCTION OF CAVITY BEAM POSITION MONITORS FOR THE ARES ACCELERATOR AT DESY

D. Lipka*, M. Holz, S. Vilcins
Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany

Abstract

The SINBAD facility (Short and INnovative Bunches and Accelerators at DESY) hosts various experiments in the field of production of ultra-short electron bunches and novel high gradient acceleration techniques. The SINBAD facility, also called ARES (Accelerator Research Experiment at SINBAD), is a conventional S-band linear RF accelerator allowing the production of low charge ultra-short electron bunches within a range between 0.5 pC and 1000 pC. The positions of the low charge bunches will be detected by cavity beam position monitors. The principal design is based on the experience from the Eu-XFEL cavity beam position monitors. It consists of a 316 LN stainless steel body with a design loaded quality factor of 70, a resonance frequency of 3.3 GHz and a relative wide gap of 15 mm to reach a high peak position sensitivity of 4.25 V/(nC · mm). This poster covered, the manufacture of the individual mechanical parts, as well as presents the special features in the manufacture of customer designed UHV feedthroughs.

MOTIVATION

SINBAD is a dedicated accelerator R&D facility at DESY, Hamburg, and hosts the ARES linac (Accelerator Research Experiment at SINBAD). It consists of a normal conducting photo-injector and a 100 MeV S-band linear accelerator with beam repetition rates between 10 and 50 Hz for the production of low charge beams (0.5-30 pC) with (sub-) fs duration and excellent arrival time stability [1–4]. For dedicated user experiments bunch charges up to 1000 pC are foreseen. To observe the beam transverse position with highest precision the requirements include a resolution of 5 µm for a beam charge between 5 and 100 pC. To achieve this requirement a cavity beam position monitor (CBPM) is developed.

DESIGN

The CBPM consist of 3 stainless steel discs brazed together which forms the dipole and reference resonators. The dipole mode of the dipole resonator is coupled with 4 symmetric slots to reduce the influence of the monopole mode of the same dipole resonator [5]. The distance of both resonators is chosen to reduce the influence of the reference resonator monopole mode below −100 dB in the dipole resonator mode because both have the same frequency and would add a beam offset, this value corresponds to a maximum of 0.1 µm position offset. The antennas are coupled to the magnetic field of the resonance with multi-contact springs in the body which results in a connection in the body and therefore can not be used for tuning. In general the design is optimized to avoid any tuning in frequency and quality factors by defining all mechanical tolerances small enough to be prepared for mass production. The feedthroughs are connected to the body with flanges to be able to exchange them in case of failure, see Fig. 1. The design values are shown in Table 1.

Table 1: CBPM Design Properties [6]

	Dipole	Reference
f_L	3300.0 MHz	
Q_L	69.9	68.9
Q_0	1264	514
Q_{ext}	74.1	79.6
S	4.25 V/(nCmm)	44.5 V/nC

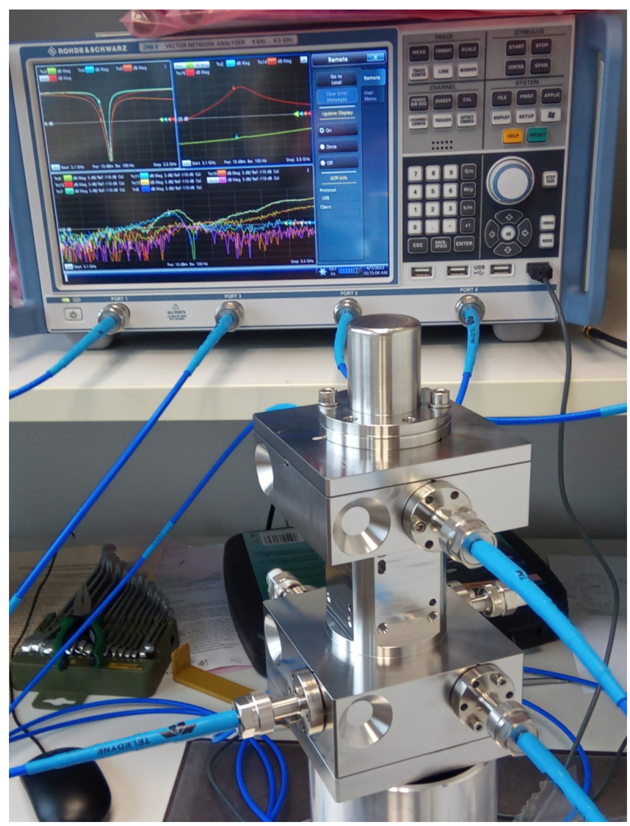

Figure 1: Photo of the CBPM in the laboratory during NWA measurement.

The design is similar to the one for the Eu-XFEL where a low quality factor is required for single bunch measurement with bunch repetition rate of up to 4.5 MHz [7]. The basis

* dirk.lipka@desy.de

ISBN: 978-3-95450-241-7 ISSN: 2673-5350 doi:10.18429/JACoW-IBIC2022-MOP12

is the design for SACLA [8]. The resonance frequency of 3.3 GHz is chosen because of the relative large beam tube of 34 mm such that the cut-off frequency is still higher. These design properties are similar to other already designed CBPMs at DESY for synergy reasons.

INFLUENCE OF FEEDTHROUGH

The RF design does not consider any influence of the feedthroughs. But during laboratory measurements an influence to the external quality factor was observed. Therefore the design of the feedthroughs are investigated with respect to the resonators of the CBPM. In Fig. 2 the dipole and the reference resonator external quality factors are simulated with the Computer Simulation Technology Studio Suite [9]. The feedthroughs are connected on the body with real distances and the permittivity of the isolator is varied. This results in a certain reflection which changes the external quality factor. In this simulation the permittivity is assumed to be the reason of the reflection but other reasons cause this reflection as well e.g. asymmetry of pin to the feedthrough body or different steps of the isolator and so on. The problem

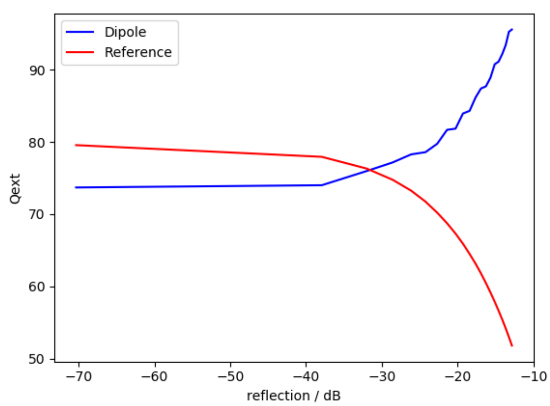

Figure 2: External quality factor as a function of feedthrough reflection for both resonators at 3.3 GHz.

of feedthrough reflection for the external quality factor is visible in Fig. 2 that with reflections above −40 dB the values diverge and causes larger differences in the loaded quality factor for both resonances. This means the dipole signal will gain a longer and the reference signal has a shorter decay time and the sensitivity for peak measurements is affected. The resonance frequency of both resonators are influenced too, see Fig. 3. Fortunately both frequencies are affected in the same manner and the difference of both resonance frequencies are small. The electronics could cover the change of frequency.

To compensate the influence of higher reflection one could change the distance of the feedthrough to the resonator; but this implies additional flanges and inner pin length which is difficult to realize and the influence of the connector and cable could add another change of the quality factor. Another possibility is to decrease the inner diameter of the

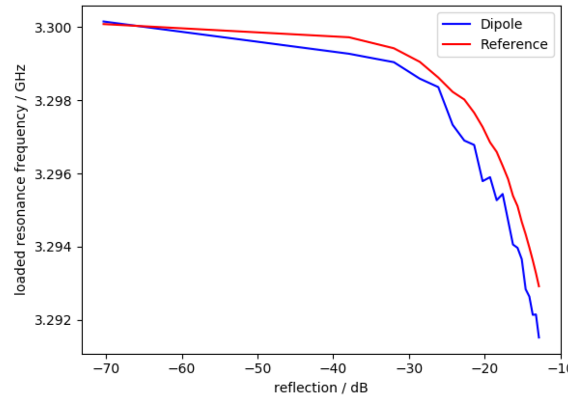

Figure 3: Resonance frequency as a function of feedthrough reflection for both resonators at 3.3 GHz.

gasket such that the reflected signals are compensated. But in simulation the compensation of reflections goes together with reduction of the sensitivity. Therefore feedthroughs with low reflections at the resonance frequency is required of <−30 dB. Still this will change the resonator properties but can be accepted and feedthrough companies should be able to produce them.

FEEDTHROUGH RESULTS

To verify the reflection of feedthroughs one needs a test-setup to avoid reflections at the open end. A possibility to measure the reflection is to mount two feedthroughs together with a certain gasket and pin to minimize the gap in between, see Fig. 4. This increases the reflection of this system

Figure 4: Photo of setup to measure reflection of two feedthroughs.

from a single feedthrough but can be compared with simulation of both together. We used feedthroughs which were developed together with the company BC-Tech in Switzerland [10]. The results of the reflection of a production in 2020 is shown in Fig. 5. The reflection at the resonance frequency of 3.3 GHz is larger compared to the simulation. In addition we investigated the homogeneity of the feedthrough isolator and found enclosed air volume within the isolator which is an indication of non-tightness. Measurements on the feedthroughs verified that few of them was not tight. The reflection of the system is about −20 dB which results that the single feedthroughs end up with about −25 dB. New production in 2022 where the design has been adapted to avoid enclosed air volume in the isolator and results in smaller

ISBN: 978-3-95450-241-7 ISSN: 2673-5350 doi:10.18429/JACoW-IBIC2022-MOP12

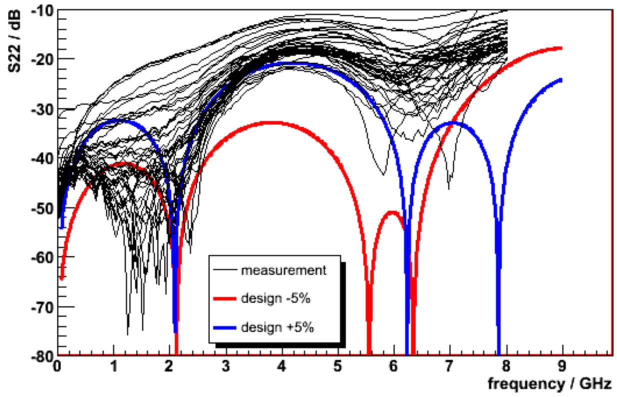

Figure 5: Reflection of two feedthroughs production at 2020 with expected reflections of the system by varying the permittivity by ±5%.

reflections, see Fig. 6. The production in 2022 show again higher reflection than simulated but is better compared to the production in 2020. For measurement of the CBPM mostly the feedthroughs with high reflection from 2020 are used until we observed a significant change of the external quality factor. Afterwards we used feedthroughs with lower reflection from the production of 2022.

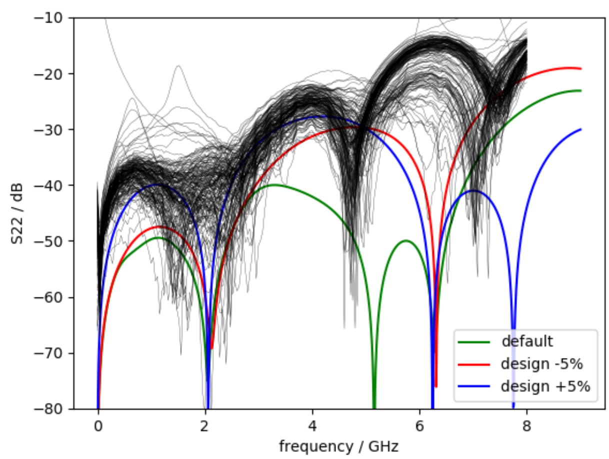

Figure 6: Reflection of two feedthroughs production at 2022 with expected reflections of the system by varying the permittivity by ±5%.

BODY MANUFACTURING AND MATERIAL

For this project, 25 CBPMs were fabricated from forged 316 LN ESR material at three different manufacturers. The raw material came from two different batches and was provided by DESY. The design was developed at DESY and all necessary technical documentation was also provided. The CBPM have CF flanges integrated directly into the body of the components. The aim is thus to obtain a compact design with the smallest possible dimensions.

If these components are then exposed to temperatures required for brazing, 316 LN ESR may loose some hardness. An example for this is shown in Fig. 7 where the hardness of a 316 LN ESR flange was measured before and after a heat treadment of 1110 °C (same procedure than for brazing). Thus, there are two challenges to overcome on these components, the first are the very tight tolerances and the second is compliance with ultra-high vacuum conditions of these parts better than 1×10^{-10} mbar leak rate.

197,5	------>	146,4
195,3	------>	144,5
199,8	------>	145,9
203,2	------>	146,4

Figure 7: Hardness measurements of 316 LN ESR before and after heat treatment with 1110 °C at four different position on the flange. The values are in Brinell Hardness (HB).

All three manufacturers have supplied components within specifications, but there are always discrepancies. These include component cleanliness (smaller threads and deep holes), surface finish, fits, and the manufacture of milled CF knife edges. The latter presents challenges for any manufacturer. The results of which very strongly influence the quality of the CF sealing area. The loss of hardness is a critical device criterion. Therefore a new material for the production of such devices is under development. First tests with the material 1.3964 (ESU) showed superior hardness properties. Further test with detailed heat treatment are foreseen in the future.

CBPM RESULTS

The resonance frequencies and quality factors of the CBPMs are measured in the laboratory before brazing the discs together, after brazing and after final mounting. These steps are chosen to identify problems as earliest as possible to be able to react on discrepancies. The measurements are

ISBN: 978-3-95450-241-7 ISSN: 2673-5350 doi:10.18429/JACoW-IBIC2022-MOP12

Table 2: Resonance Frequency in MHz

	Dipole	Reference
before brazing	3291.4 ± 1.6	3294.7 ± 6.4
after brazing	3293.1 ± 2.5	3294.3 ± 5.4
final assembly	3290.5 ± 1.2	3294.9 ± 1.4

done with a 4-port network analyzer and the reflected data are analyzed according [8].

In Table 2 the resonance frequency results are listed of all produced CBPMs according the mentioned steps. Not all CBPMs are already brazed and finally assembled: 25 CBPMs are measured before brazing, 11 after brazing and 8 after final assembling. Therefore the results presents different amount of CBPMs. The dipole resonance frequency is lower compared to the reference resonator which is according to the simulation result shown in Fig. 3. But the used feedthroughs for final assembling was with low reflection therefore a higher resonance frequency was expected from simulation. In Table 3, the loaded quality factor results are shown. Note that with low reflected feedthrough after final assembling the dipole quality factor becomes near to the design value; still the reference quality factor is lower than required. Fortunately the expected electronics will cover the difference [11]. The sensitivity of all 8 final assembled CBPMs are (4.482 ± 0.056) V/(nC · mm) for the dipole resonator and (48.1 ± 0.9) V/nC which is already larger than expected from simulations.

Table 3: Loaded Quality Factor

	Dipole	Reference
before brazing	85.2 ± 11.2	56.9 ± 3.7
after brazing	80.2 ± 7.8	63.0 ± 4.7
final assembly	73.6 ± 1.6	59.6 ± 1.9

SUMMARY

We produced some CBPMs for ARES. During production we observed an influence of the feedthrough to the dominating external quality factor. Therefore feedthroughs with low reflections are required which are produced, improved and re-produced. The stainless steel needs attention to keep the hardness during the brazing process.

REFERENCES

[1] U. Dorda *et al.*, "The Dedicated Accelerator R&D Facility Sinbad at DESY", in *Proc. IPAC'17*, Copenhagen, Denmark, May 2017, pp. 869–872. doi:10.18429/JACoW-IPAC2017-MOPVA012

[2] B. Marchetti *et al.*, "Status Update of the SINBAD-ARES Linac Under Construction at DESY", in *Proc. IPAC'17*, Copenhagen, Denmark, May 2017, pp. 1412–1414. doi:10.18429/JACoW-IPAC2017-TUPAB040

[3] E. Panofski *et al.*, "Status Report of the SINBAD-ARES RF Photoinjector and LINAC Commissioning", in *Proc. IPAC'19*, Melbourne, Australia, May 2019, pp. 906–909. doi:10.18429/JACoW-IPAC2019-MOPTS026

[4] F. Burkart *et al.*, "The Experimental Area at the ARES LINAC", in *Proc. IPAC'19*, Melbourne, Australia, May 2019, pp. 867–870. doi:10.18429/JACoW-IPAC2019-MOPTS014

[5] V. Balakin *et al.*, "Experimental results from a microwave cavity beam position monitor", in *Proc. PAC'99*, New York, USA, March 1999, pp. 461–464. doi:10.1109/PAC.1999.795732

[6] D. Lipka, M. Dohlus, M. Marx, S. Vilcins, and M. Werner, "Design of a Cavity Beam Position Monitor for the ARES Accelerator at DESY", in *Proc. IBIC'18*, Shanghai, China, Sep. 2018, pp. 269–272. doi:10.18429/JACoW-IBIC2018-TUPB05

[7] D. Lipka, D. Nölle, M. Siemens, and S. Vilcins, "Development of Cavity BPM for the European XFEL", in *Proc. LINAC'10*, Tsukuba, Japan, Sep. 2010, paper TUP094, pp. 629–631.

[8] H. Maesaka *et al.*, "Sub-micron resolution rf cavity beam position monitor system at the SACLA XFEL facility", *Nucl. Instrum. Methods Phys. Res., Sect. A*, vol. 696, pp. 66-74, 2012. doi:10.1016/j.nima.2012.08.088

[9] Computer Simulation Technology, http://www.cst.com

[10] BC-Tech AG company, https://bctech.ch/.

[11] B. Lorbeer *et al.*, "Cavity BPM Electronics for SINBAD at DESY", presented at IBIC'22, Krakow, Poland, Sep. 2022, paper WEP14, this conference.