ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-THPOPT053

GOUBAU-LINE SET UP FOR BENCH TESTING IMPEDANCE OF IVUE32 COMPONENTS

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Abstract

The worldwide first in-vacuum elliptical undulator, IVUE32, is being developed at Helmholtz-Zentrum Berlin. The 2.5 m long device with a period length of 3.2 cm and a minimum gap of about 7 mm is to be installed in the BESSY II storage ring. It will deliver radiation in the soft X-ray range to several beamlines. The proximity of the undulator structure to the electron beam makes the device susceptible to wakefield effects which can influence beam stability. A complete understanding of its impedance characteristics is required prior to installation and operation, as unforeseen heating of components could have catastrophic consequences. To understand and measure the IVU's impedance characteristics a Goubau-line test stand is being designed. A Goubau-line is a single wire transmission line for high frequency surface waves with a transverse electric field resembling that of a charged particle beam out to a certain radial distance. A concept optimized for bench testing IVUE32-components will be discussed, microwave simulations will be presented together with first measurements from a test stand prototype.

INTRODUCTION

BESSY II is a third generation synchrotron light source with an electron beam energy of 1.7 GeV. There are 32 dipole magnets and 13 undulators supplying 48 beam lines with radiation ranging from infrared to soft X-ray. In September of 2018 the first in-vacuum undulator (IVU) CPMU17 [1] was installed in BESSY II to provide hard X-rays for the Energy Materials In-Situ Laboratory (EMIL) [2]. As described in previous proceedings [12,13] IVUs require shielding foils between their magnets and the accelerator beam. The second IVU for BESSY II, IVUE32 [10], is currently under development. The APPLE II configuration poses even greater design challenges than the planar CPMU17. IVUE32 features four individually movable magnet rows which requires a longitudinal slit in the shielding foils. The split shielding foils further complicate the design of the transition taper between the beam pipe and the undulator magnets.

Motivation

Without a vacuum chamber wall between the beam and the undulator magnets, both CPMU17 and IVUE32 change their geometry from a collimator to a cavity over the entire gap range. This has an impact on wakefield characteristics and beam dynamics. The impact on beam stability is difficult to simulate. Beam based impedance measurements using orbit bump and tune shift methods have been done for the already installed CPMU17 with different gap settings [3]. Grow-damp and drive-damp methods have been utilized as well by M. Huck *et al.* [4].

The novel design of IVUE32 brings even more challenges as the shielding foil is split in the middle longitudinally to accommodate the different polarization settings. Therefore the impact on beam stability and accelerator operation are difficult to simulate and predict. Being able to measure impedance outside of the running accelerator is desirable to avoid complicated down time.

As introduced in [12] a Goubau-line test stand is a possible way to measure impedance of insertion devices. Designed by Georg Goubau in 1950 [5] based on the work of Sommerfeld from 1899 [6], a Goubau-line is a transmission line that uses a single wire to transmit surface waves. Its transverse electric field can be used to mimic that of a charged particle beam. Goubau-line set ups have been successfully used to measure the impedance of accelerator components, for example at Argonne APS [7] or at Bergoz Instrumentation [8]. Studies of CPMU17s impedance suggest that the fill pattern at BESSY II induces effects up to a frequency of 20 GHz which is significantly higher than the aforementioned test stand examples.

The following sections will show CST [11] simulations of the proposed Goubau-line design and discuss design parameters.

THEORETICAL CONSIDERATIONS

The main parts making up a Goubau-line are a transmitter, a receiver and a dielectrically coated wire. Horn antennas are used as transmitter and receiver shown in Fig. 1. The

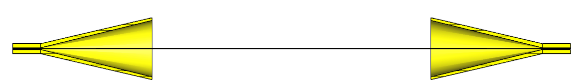

Figure 1: Schematic of the Goubau-line modeled in CST consisting of two conical horn antennas and a dielectrically coated wire.

Horn antennas translate the signal coming from a coaxial cable to a surface wave on the dielectrically coated wire. Figure 2 shows the orientation of electric and magnetic fields along the coated wire. The electric and magnetic Fields are described by cylinder functions and their derivation is shown in Goubau's original paper [5] and in a modern revision by B. Vaughn *et al.* [9]. The radial electric field E_r is proportional to $1/r$ close to the coated wire and can therefore be used to emulate a charged particle beam before falling off exponentially at greater distances from the wire. In previous proceedings we discussed the wire parameters of the Goubau-line test stand by considering field extension and characteristic impedance [12, 13]. A 1 mm diameter copper wire with a 500 nm coating with a dielectric constant of $\varepsilon_r = 4$ was chosen. Extensive CST simulations have been

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13th Int. Particle Acc. Conf. IPAC2022, Bangkok, Thailand JACoW Publishing
ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-THPOPT053

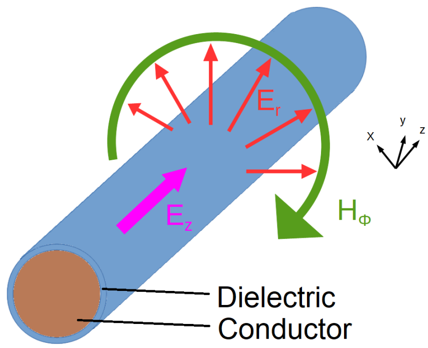

Figure 2: Schematic of field orientation of a Goubau-line. The transverse electric field E_r mimics the field generated by a charged particle beam.

done to test the design parameters. The effects of the dielectric coating on the wire and taper have been investigated.

DIELECTRIC COATING

Three versions of the proposed Goubau-line have been simulated using CST studio suit: both the wire and taper are coated, only the wire coated, and neither coated. The S_{21}-parameter compares the transmitted signal to the incoming signal. It is a measure of transmission as a function of frequency. To achieve a low signal to noise ratio when using the Goubau-line test stand, the transmission of the Goubou-line itself must be optimized over the desired frequency band. The S_{21}-parameter for the three simulated cases is shown in Fig. 3. The signals for all three cases are very similar. Only the case without coating can be discerned from the other two at the low frequency end.

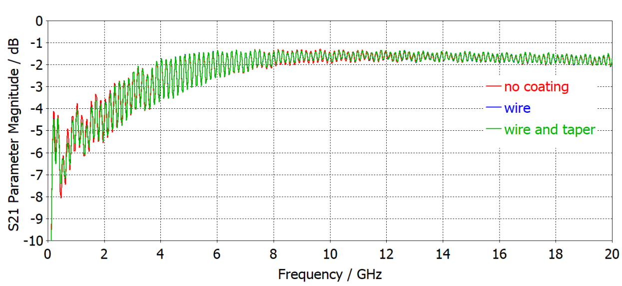

Figure 3: Quality of transmission of simulated Goubau-line as a function of frequency. The S_{21}-parameter is shown for the Goubau-line with no coating, with the coated wire, and with both wire and taper coated. The coating seems to have a very limited effect on transmission.

Another tool to evaluate the Goubau-line is Time Domain Reflectometry (TDR), which compares the incoming time signal to the reflection at a port. The corresponding impedance is then calculated. From that time signal the location of a reflection source in the structure can be determined. Reflection sources are usually impedance discontinuities. Analyzing the TDR-signal, areas in the structure can be identified where impedance matching needs to be improved. Figure 4 shows the TDR time signal for the three cases with the schematic of the Goubau-line shown underneath the time axis for a rough estimate which part of the structure corresponds to the impedance changes. As with the S_{21}-parameter, the coating of the taper seems to have no significant effect. The uncoated Goubau-line has a noticeably higher impedance signal after 5 ns. This corresponds to the surface wave encountering the receiving cone antenna. The dielectric coating of the wire attenuates the expansion of the radial electric field. Therefore the field of the uncoated wire extends further and interacts stronger with the receiver, causing more reflections.

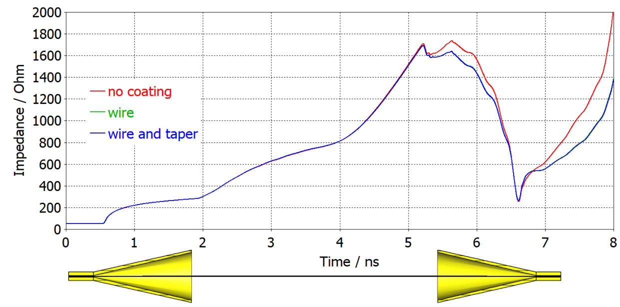

Figure 4: Time Domain Reflectometry of simulated Goubau-line with the schematic below the time axis as a rough reference to what part of the structure corresponds to the impedance changes. TDR signal is shown for the Goubau-line with no coating, with the coated wire, and with both wire and taper coated. The case without coating shows a stronger signal when entering the receiving cone.

OUTLOOK

Having found a functional Goubau-line design, further simulations are in progress to test the behavior when structures are placed in the radial Field of the wire. A simple cavity shown in Fig. 5 has been simulated together with a reference structure. The device under test (DUT) is placed around the wire in the middle of the Gouboa-line. M. P. Sangroula, *et al.* describe how they calculate the impedance of structures from the measured S_{21}-parameters [7]. We are currently trying to reproduce their method with our simulations. Figure 6 shows the S_{21}-parameters for the cavity and the reference beam pipe. The cavity affects the transmission for frequencies between 14 GHz and 19 GHz with peaks at 14.6 GHz, 16.2 GHz, 17.2 GHz, and 18.8 GHz. Impedance analysis from the S_{21}-parameter data is currently in progress together with wakefield simulations of the same cavity. The wakefield simulations will be a reference for the impedance obtained from the Goubau-line simulations.

CONCLUSION

The simulations show only a very limited effect of the dielectric coating of the wire. With only 500 nm the coating is very thin. This thickness has been determined to allow for enough field extension to cover the aperture of IVUE32 for a frequency range up to 20 GHz [12]. The dielectric

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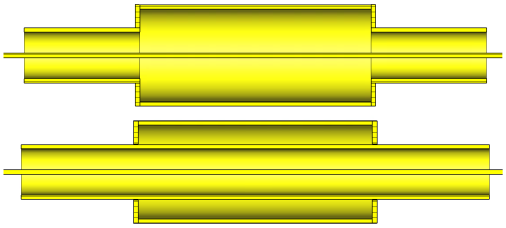

Figure 5: Simple test cavity structure shown together with the reference of a beam pipe below.

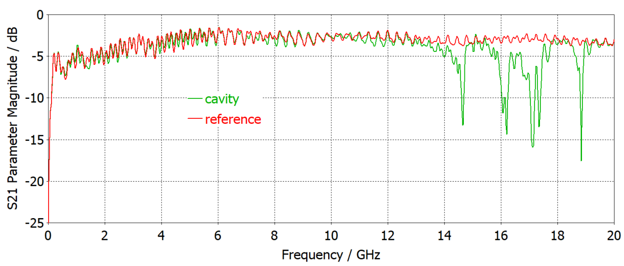

Figure 6: S_{21}-parameter for a simple cavity and the reference beam pipe. The effect of the cavity is clearly visible between 14 and 19 GHz.

coating of a Goubau-line is meant to limit the radial electric field extension in order to insure low loss transmission over long distances [5]. At such high frequencies, the field extension is limited anyhow, making an uncoated approach plausible. The uncoated transmission line was investigated by Sommerfeld [6] and was used by Goubau as a basis for his transmission line. Further investigations with regard to Sommerfeld's theoretical approach need to be taken for a final decision about the dielectric coating. There is also a possibility that CST Studio does not represent such thin coatings correctly in our simulations, which also warrants further investigation.

The simulations for the DUT look promising but are not fully evaluated yet. The simulation results justify the construction of a Goubau-line prototype in order to confirm the results. That process will be started as soon as possible.

ACKNOWLEDGMENTS

I would like to thank Günther Rehm for his discussions and advice regarding high frequency instrumentation and Frank Stulle for sharing his experience regarding Goubau-lines.

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