EXPERIENCE WITH A BROADBAND CAVITY AT COSY

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Abstract

We describe the integration of a broadband cavity based on the material VitroPerm into COSY [1]. The electrical characteristics of the 12 cores arranged in two half-cavities allow the application of a fundamental from 400 kHz to 1.6 MHz together with 2 higher harmonics. The second harmonic can be driven at up to 50 % amplitude, the third or fourth harmonic at 20% amplitude of the fundamental. The impedance is a function of the magnetic material and also of the cooling medium. We measure the impedance with tap water, low conductivity water and Fluorinert FC_77. Like colleagues from KEK [2] we obtained at least 400 Ω. The acceleration voltage requirements of COSY allow beam tests with this cavity by semiconductor amplifiers in the kW power range. We plan an upgrade to a tube amplifier with 50 kW RF power, to compare different schemes of γ-transition crossing.

1 FIRST ASSEMBLY

In 1999 we measured the impedance of each half of the cavity structure loaded with VitroPerm [3], [4]. With water of different quality as cooling medium we noticed that the impedance is related to the water purity, e.g. tap water resulted in about half the maximum impedance, compared to low conductivity water, see Fig. 1. The lower impedance explained as a reduced Q with tap water could be an advantage for broadband operating, because the impedance variation vs. frequency is lower. We do not fill both cavity sides with tap water, to prevent contamination of the low conductive water cooling system.

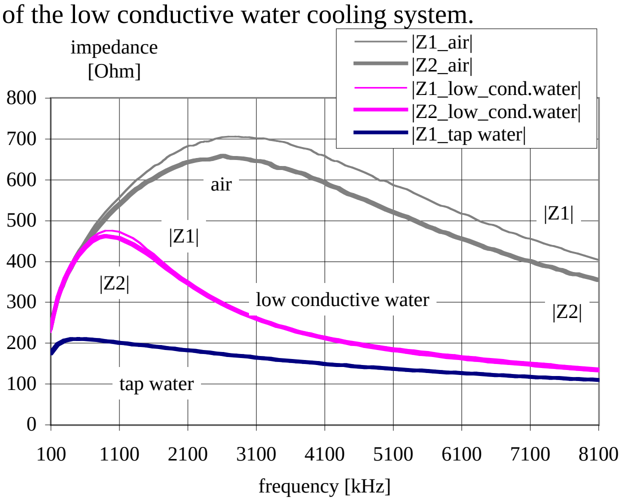

Fig. 1: Impedance as function of cooling medium, measured on both cavity sides 1 and 2 separately

We experienced problems with corrosion of the cores, because the coating, comparable to resin used for transformer metal sheets, was not perfect waterproof. The manufacturer of the cores [5] removed the coating and the corrosion and made tests to improve the water protection. The final solution is to bandage the cores with glass-fiber to increase the adhesion and then to apply the resin. As a finish the cores were painted with a waterproof color.

These tests of different coatings resulted in a reduction of the impedance value of the cores due to thermal stress when heating up the cores with the resin.

2 SECOND ASSEMBLY

When the cores were returned, we measured the impedance of each core with a single turn winding. The absolute value is plotted in Fig. 2. The 12 cores were sorted in two groups to get almost equal impedance as a function of frequency on both cavity sides. The result of the optimization – both cavity sides loaded with VitroPerm and no cooling medium, e.g. only air, is demonstrated in Fig. 3.

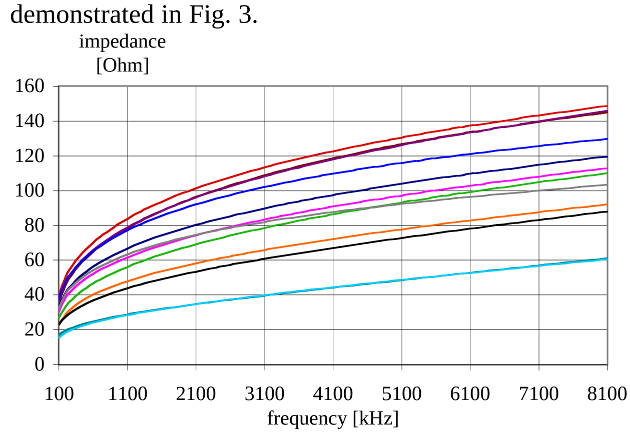

Fig. 2: Impedance distribution of 12 cores

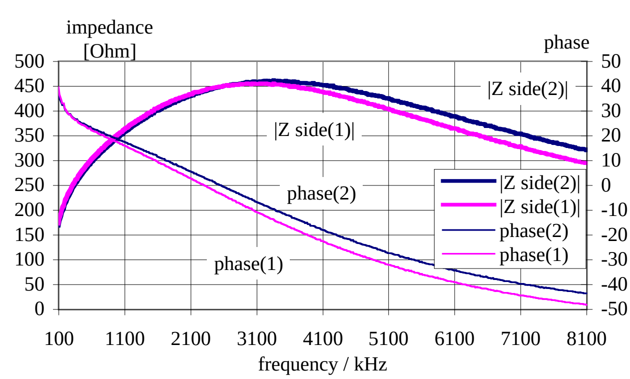

Fig. 3: Impedance of both sides of VitroPerm cavity filled with air

3 SMALL TEST CAVITY

The impedance as a function of cooling medium is measured with a test-cavity representing one cavity side. The impedance of a group of 3 small sample cores (outer dia. 76 mm, inner dia. 50 mm, height 25mm) of the same material grade and coating is plotted as a function of coolant in Fig. 4. This confirms [2], that Fluorinert FC_77 [6] with its dielectric constant of ε_r=1.86 does not affect the impedance compared to air. With water as coolant, it is important to use low-conductivity water instead of tap water to obtain a high impedance value. This is appropriate for operation with a fundamental and higher harmonics, which are lower than the fundamental. With tap water the lowered impedance is less sensitive to frequency, so increased power allows operation at different fundamental frequencies.

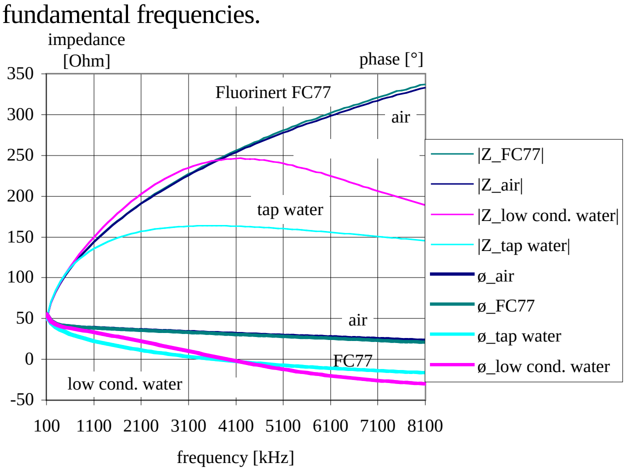

Fig. 4: Impedance of 3 VitroPerm sample cores as function of cooling medium

4 OPERATING CONDITIONS

For operation at COSY (500 kHz to 1.6 MHz), the VitroPerm cavity is filled with low conductive water. The impedance shown in Fig. 5 is lower than in Fig. 1 (first assembly). The value of ≈200 Ω per cavity side in the COSY range matches to 200 Ω custom-made transmission lines. The outer part of the coax is standard 4 1/2-inch [7]. Inside it is modified to 4mm inner diameter.

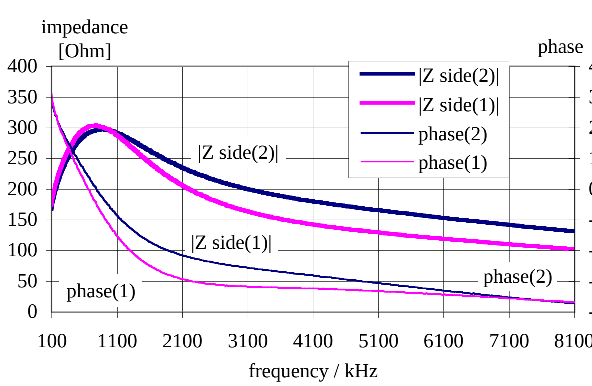

Fig. 5: Impedance of both sides of low-conductive water-filled VitroPerm cavity; second assembly

In 100 mm diameter size, 2 VitroPerm cores are used for impedance transformers/combiners at the end of the transmission lines. The 50 Ω output impedance of one transistor amplifier is transformed (1:9) to 450 Ω. Two amplifiers are combined on one core and thus matched to 225 Ω. This layout is shown in Fig. 6. For higher power we will drive the cavity with a push-pull tube amplifier via the transmission lines.

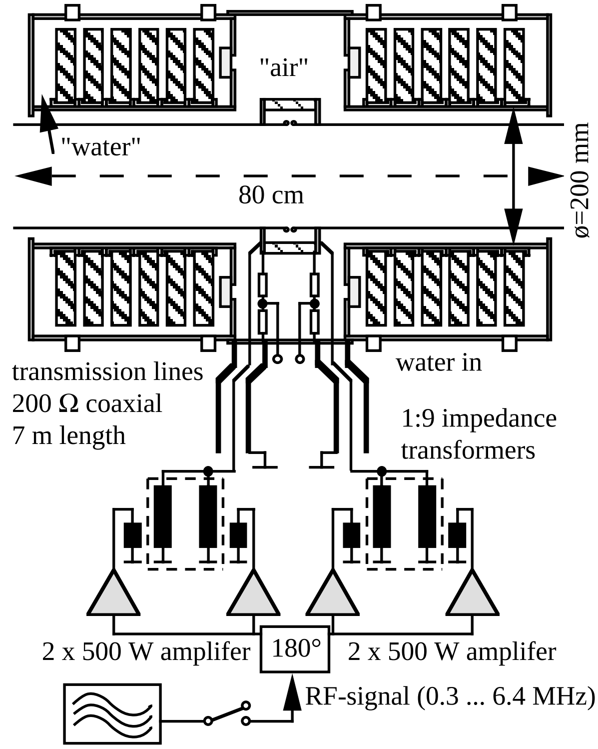

Fig. 6: Layout of cavity, transmission lines, transformers and amplifiers

The voltage plotted in Fig. 7 is high enough to operate COSY with only 2 kW delivered by 4 amplifiers.

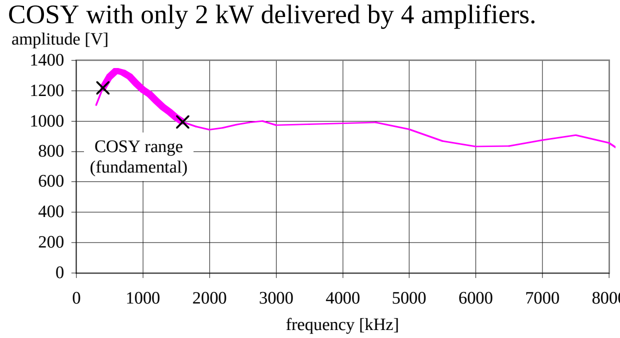

Fig. 7: Cavity voltage for -3dBm amplifier input.

So, the cavity was installed in COSY and brought into operation with beam. First we demonstrated, that the performance of the VitroPerm cavity, measured as ratio of accelerated beam in flat top over injected particles compared to the ferrite cavity is at least the same when we operate it with the fundamental only. By adding the second harmonic [8] in the VitroPerm cavity the bunching efficiency [9], [10] increases as shown in Figs. 8a-b. This results in about 10 % more particles in flat-top.

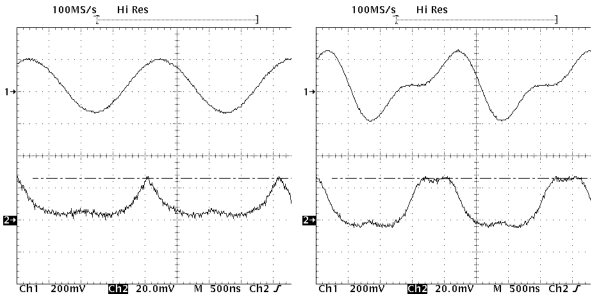

Fig. 8: Bunching at 300 MeV/c with
a) fundamental (h=1) only b) harmonics (h=1) and (h=2)

From operation of the cavity we learned, that the cooling water for the cavity should not be too cold to prevent condensation of humidity. We also inserted a relay in the signal path to the amplifiers: In flat-top we program zero amplitude to de-bunch the beam. The synthesizer output is "quiet" at the generated harmonics, but there is some crosstalk of the digital clock at $16xf_{rev}$. This affects the beam via the broadband amplifiers and cavity. We observed and corrected this.

5 SIGNAL SYNTHESIS

For signal synthesis of the higher harmonics we program signals with a predictable amplitude - an example is given in Fig. 9. For real operation amplitude and phase of the higher harmonics are adjusted to the fundamental. This relation is shown for (h=2) to (h=1) in Fig. 10.

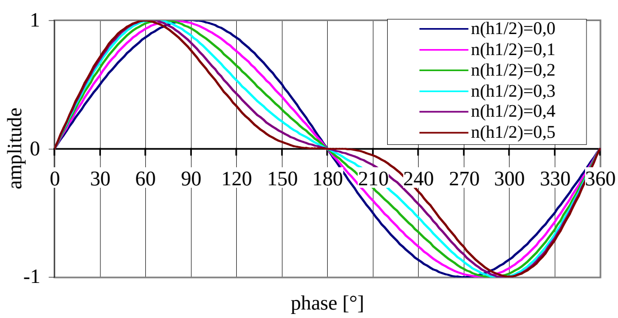

Fig. 9: Combined h=1, 2 with compensated amplitude

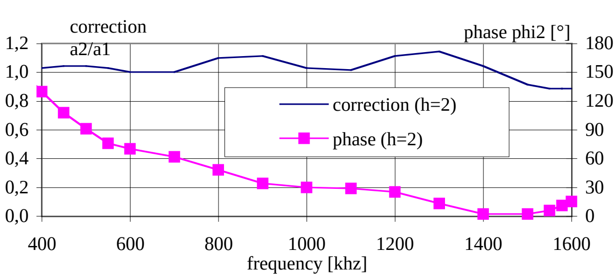

Fig. 10: Measured phase and amplitude relation between harmonics (h=1) and (h=2)

6 NEXT EXPERIMENTS

We will compare the VitroPerm cavity with beam experiments at COSY, where we cross γ-transition (see Fig. 11) without using the Q-jump-system – only by applying a phase program to the digital phase loop of the RF-system. We will need more power for the VitroPerm cavity, and therefore we plan to drive it with a push-pull tube amplifier, which was used for the VitroVac cavity [11] for TERA [12] before.

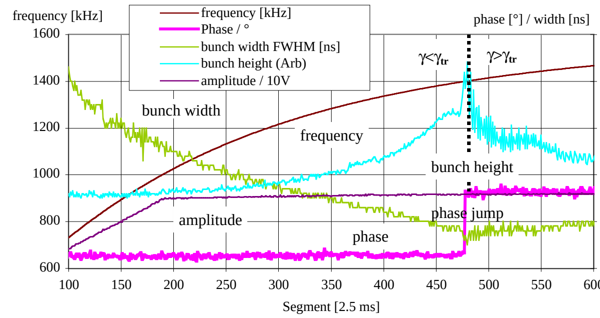

Fig. 11: γ-transition crossing at COSY with ferrite cavity and adjusted phase-jump

ACKNOWLEDGEMENT

I want to express my thank to colleagues from KEK who shared their experience [13] how to build and operate cavities loaded with magnetic alloys.

REFERENCES

[1] H. Stockhorst et. al., "The Medium Energy Proton Synchrotron COSY", EPAC2000, Vienna, 2000
[2] M. Yoshii et. al., "MA RF Cavity for the KEK 12 GEV PS", EPAC 2000, Vienna, June 2000
[3] M. Böhnke et. al., "Broadband Synchrotron Cavity for COSY with Minimum Size based on VitroPerm", Proc. PAC 99, p. 851-853, New York 1999
[4] A. Schnase et. al., "Preparing a Broadband Cavity for Installation at COSY", IKP Annual Report 1999, Jül-3744, p. 150-151, FZ Jülich, 2000
[5] Vacuumschmelze Hanau GmbH, "Kerne und Bauelemente", Datenbuch 1998
[6] 3M, Fluorinert Electronic Liquid FC - 77, Specialty Materials, 3M Center, Building 223-6S-04, St. Paul, MN 55144-1000, USA, see www.3m.com/fluids
[7] Connector Catalogue 3, "Coaxial Rigid Lines and Components", Spinner GmbH, München, 1997
[8] H. Stockhorst, "Longitudinal Beam Dynamics in a Multiple Harmonic RF-System", IKP Annual report 1994, Jül-3035, p. 233-235, FZ Jülich, 1995
[9] R. Muramatsu et. al., "The First Beam Acceleration Test Using High Gradient Cavity at HIMAC", Proc. PAC 99, p. 798-799, New York 1999
[10] M. Yamamoto et. al., "Multi-Harmonic Acceleration with High Gradient MA-Cavity At HIMAC", Proc. PAC 99, p. 863-865, New York 1999
[11] P. Ausset et. al., "A Broad-Band (0.2-8MHz) Multiple-Harmonic VITROVAC®-Filled Acceleration Structure", EPAC 94, p. 2128ff, London 1994
[12] M. Crescenti, et. al., "The VITROVAC® RF Cavity in the TERA/PIMMS Medical Synchrotron", EPAC 2000, Vienna, June 2000
[13] C. Ohmori et. al., "High Field-Gradient Cavities Loaded with Magnetic Alloys for Synchrotrons", Proc. PAC 99, p. 413-417, New York 1999