SUPERCONDUCTIVE ACTIVITIES AT COSY FZJ

R. Stassen, W. Bräutigam, O. Felden, M. Glende, A. Lehrach, R. Maier, A. Schnase, G. Schug, Y. Senichev, R. Tölle, E. Zaplatin, Forschungszentrum Jülich, Germany

Abstract

A shielded test facility has been constructed to allow RF tests of superconductive (sc) cavities. Measurements of sc cavities are possible up to 500W in a frequency range from 80MHz to 1GHz. Additionally a 25kW TV transmitter has been installed together with a high power circulator. The first sc experience has been made at a 5-cell 500 MHz, β=0.75 test cavity for the ESS. First quasi-static measurements using the 500W broadband amplifier almost verified the design values of $Q_0=2\times10^9$ and E_{acc}>5MV/m. The tuning system of the cavity consists of a coarse system driven by a stepper motor and a piezoelectric fine tuner. The piezoelectric tuning system has been used to record the spectrum of mechanical resonances of the cavity. Furthermore, dynamical data of the Lorentz force detuning have been taken during pulsed-mode operation at a repetition rate of 50Hz. First results of active compensation of the Lorentz force detuning, using the fast piezo frequency control system, are presented. A digital diagnostic tool has been added to measure the phase in the order of 0.1° which will be required for a fast digital control system. A vertical cryostat down to 2K will be installed in the test area to perform studies for the planned multicell spoketyp, elliptical cavities and QWRs. The QWRs are proposed for the LINAC project, which will feed the Cooler Synchrotron COSY with protons and deuterons up to 50MeV.

1 TEST AREA

A 30m²-shielded area has been arranged to operate superconductive cavities in horizontal or vertical cryostats [1]. Infrastructure like cooling water, compressed air as well as a local area network for computer-controlled equipment is available. A low-speed VXI system is used to survey the temperatures inside the cavity and to control the vacuum pressures. The data (26 channels) are taken every 1.5 minutes and are stored into files to get the history of the temperature and pressure behaviour of the cavity.

Liquid helium is delivered in dewars of 500 to 1000 litres, which are placed outside the radiation shielding. The LHe is filled into the helium tank of the cavity through a transferline (length ~ 9m). The cold-head of a Gifford McMahon cryogenerator connected to the thermal shield reduces the losses by about 1/3. The Lhe consumption without RF power amounts to 600 l per day. The He level in the cavity tank is maintained by an on-off control via the He pressure in the dewar. The flue gas is warmed up to room temperature and send via a gasline to the central refrigerator. Here it is cooled down to 4 K and again stored in dewars. The next step will be the installation of additional pumps to reduce the helium pressure in order to take RF measurements at 2K.

There are two RF transmitters available. The first one is a broadband (80MHz-1000MHz) 500W amplifier. We can switch from the 500W amplifier to a SIEMENS 25kW transmitter on loan from ACCEL. We serviced that transmitter and incorporated it into a high power system with a circulator and a high power switch. That allows tests of the 25kW transmitter and simultaneously uses the 500W amplifier for cavity tests or vice versa.

2 ESS TEST CAVITY

The first RF measurements were done during the acceptance tests of the ESS [2] test cavity delivered by ACCEL [3]. We took the Q_o-E_{acc} curve at nearly critical coupling in order to measure Q_0 as accurate as possible. These results well agree with those measured at CERN in a vertical cryostat and at a limited RF power of 200W. Using the 500W amplifier we can achieve accelerating fields up to nearly 8MV/m without detecting a quench, but the measured Q_0 degradation at increasing RF field strength and the monitored x-ray levels point to active field emitters inside the cavity. At higher field levels we also saw moving light spots on the vacuum window (glass), which seem to be generated by strong electron loading. A brown film tarnished even the mirror installed outside the cavity to allow an indirect view with a camera. The estimated dose of the mirror is about 30Gy during one minute.

High power Tests

The input coupler of the cavity is adjustable from nearly critical coupling to a loaded Q of the order of 1E6. We can reach a filling time of about 2ms with this coupling and 30kW RF power.

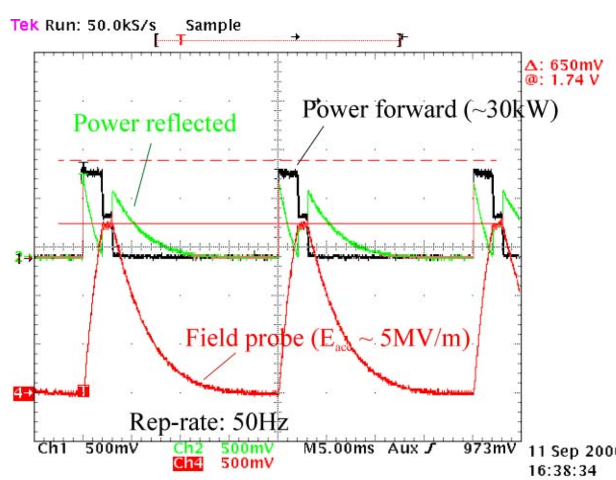


Fig.1: Pulsed operation of the ESS Test-Cavity

After filling the cavity and maintaining the flattop by switching back to 7kW to simulate the beam, the RF power is switched off 1ms later (Fig. 1).
Even at a repetition rate of 50Hz, we reached a field-level of about 5MV/m in this mode as guaranteed by ACCEL applying a forward power of about 30kW. We can operate without the phase-locked loop provided that switching off the cryopump minimizes the microphonics noise and if the system is appropriately detuned. We have conditioned the coupler and the cavity at this pulse scheme during several hours of operation with the closed phase-locked loop. The x-ray radiation detected outside the shielded area was commensurably reduced by that burn-in procedure; nearly all field emitters inside the cavity could be eliminated. Meanwhile we have reached a field level of 11 MV/m at pulse lengths of about 100ms and a repetition rate of 1Hz.

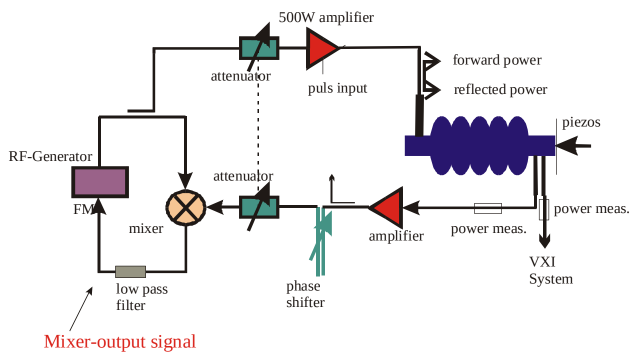


Fig. 2: RF control of the cavity

Dynamical behaviour of the cavity

Higher repetition rates such as 50 Hz for the ESS design [1] and 60 Hz at SNS [4] or 75 Hz for the CERN Neutrino Factory design [5] will require a close look into the mechanical resonances of the cavities. Such mechanical resonances can influence the phase behaviour of the cavity during a pulse that can hardly be compensated by a good control system, even if enough additional power is available.

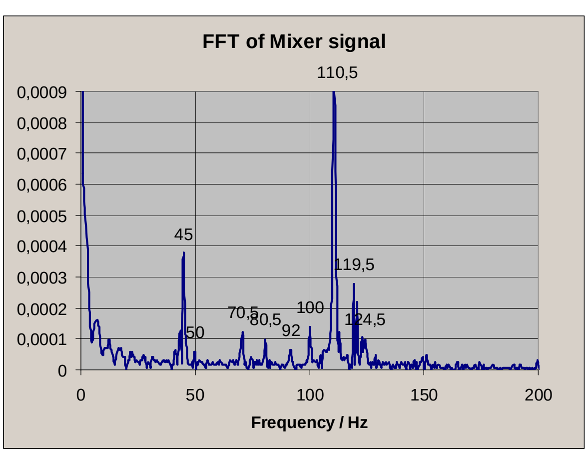
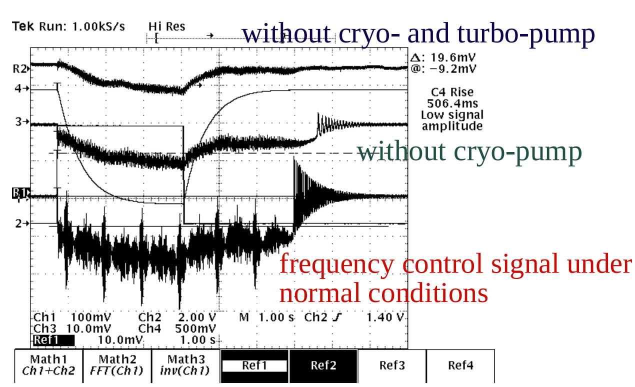


Fig. 3: FFT of the response to a 50V step function at the piezos.

We used the three piezos elements provided for the fine frequency adjustment to detect the mechanical resonances. Therefore we applied a step function in the time domain and calculated the resonances using Fast Fourier Transformation (FFT, Fig. 3).
In addition to the mechanical resonances we found the 50Hz and 100Hz components of the ripple of the AC power line. We were able to detect mechanical resonances even when applying only a low (50V) step function at the piezos. These measurements have been done stimulating all three piezos in parallel mode. Thus, mostly longitudinal resonances were excited. Even the detection system – the mixer output signal (Fig. 2) – is very sensitive to longitudinal deformations. Additional measurements are needed to separate longitudinal from transverse modes. This will be done by excitation with a separate system mounted mechanically to the support of the cavity. The three present piezos can then be used as a detection system. By means of their different mounting positions, it will be possible to decide if a transverse or longitudinal mode is excited.
Different calculations of the mechanical resonances have been carried out. The first calculation by ACCEL showed the lowest resonance far above 50Hz [6]. Further calculations including more details of the cavity in the model seem to be much closer to the measured data [7]. Future measurements are planned using the piezos elements as a diagnostic tool to directly record the vibration of the cavity in the μm range.

Microphonics

The cavity RF resonance is sensitive to vibrations of sub-μm amplitude because of the high Q. These microphonics effects cause low-frequency noise in the accelerating fields. Therefore, careful damping of cavity support and other ancillary units is necessary to suppress all vibrations of cavity. High microphonics noise in our case is produced by the 'Gifford McMahon' cryo-generator, which is connected to the cavity test cryostat to reduce helium losses.



prepared field: ~2.2 MV/m

Fig. 4: Microphonics effects by different pumps

We can see a phase oscillation corresponding to the frequency of the pump (about 1Hz). Even the effects of a turbo-pump can be seen, which demonstrates the sensitivity of the system. The microphonics cannot be reduced by feed-forward because there is no correlation to the pulse repetition rate. Hence vibration-sensitive pick-ups will be installed to build an active damping system in the future. The microphonics caused by the cryopump lead to a strong phase-shaking of more than ±20°. These phase perturbations cannot be tolerated in accelerator operation and must be mechanically compensated or regulated by a fast control system.

Lorentz force detuning

The Lorentz force detuning (LFD) in a short-pulse mode operation is normally described by the constant K and the mechanical time constant τ_{LFD}.
The frequency change due to the LFD was measured using the mixer-output signal of the frequency control system. We obtained an LFD constant of about $K=4Hz/(MV/m)^2$. Even at the relatively low design field value (5MV/m) of our test cavity, the frequency shift of about 100Hz is not negligible. The time constant τ_{LFD} of the LFD was measured during pulsed-mode operation with a pulse-length of about 10ms. We estimated a time constant of about 5ms. This high time constant allows a pulse length of 1ms like ESS without regulating circuit. Before the LFD takes place, the pulse is descending. For beam acceleration, the phase change could be corrected at lower power levels.
Fig. 5 represents the cavity behaviour of the new pulse scheme for the ESS combining a short pulse (1ms) at 50Hz and an additional long pulse (3ms) each 60ms.

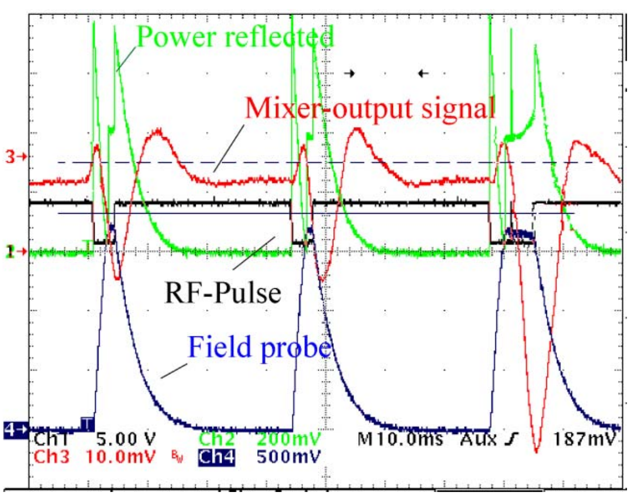


Fig. 5: Phase behaviour (mixer output signal) of the test cavity during an additional long pulse at an accelerating field of 5MV/m

The LFD leads to a so large phase shift at the long pulse that the flattop field level is descending at the end of the pulse.

Active compensation of Lorenz force detuning

Stiffening the cavities can reduce Lorentz force detuning but this method will increase the force that is necessary to tune the cavity. One way to solve this problem can be the right choice of the location of the stiffening rings [8]. Another possibility is to detune the cavity by the negative value of the average LFD and to control only the phase and amplitude change with a fast control system.
In this case large additional klystron power is needed. We have decided to compensate the LFD with a feed-forward signal because it is a predictable effect.
We used the piezos elements of the fine-tuning system because they act fast enough and can be adjusted precisely. The first approximation to compensate the Lorentz force detuning is shown in Fig. 6. Without feed-forward, we could see the change of the mixer output signal. Using a feed-forward signal in the form of one period of a sine wave, the phase stays nearly constant during flattop even at a pulse rate of 50Hz as specified in the ESS proposal.

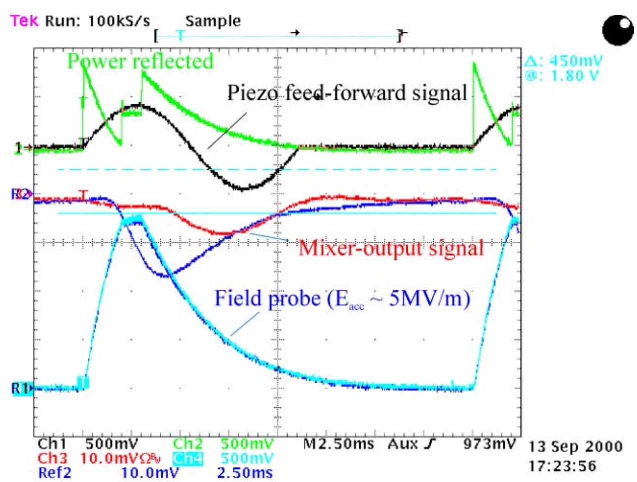


Fig. 6: Compensation of Lorentz force detuning with piezos elements. Additionally, the mixer output signal without piezos correction is drawn for comparison.

3 SPOKE TYPE CAVITIES

A field perturbation bench has been included into the RF-test area to allow automated measurements of the field profile of the copper spoketype test cavities [9].
The measurements of the model, fabricated at the central workshop at the FZJ well agree with the MAFIA calculation done by E. Zaplatin [10].
Fig. 7 shows the first field profile measurement of the 10-gap 720 MHz spoke model.
The automated system driven by a stepper motor allows many data points for an accurate measurement of the field profile.

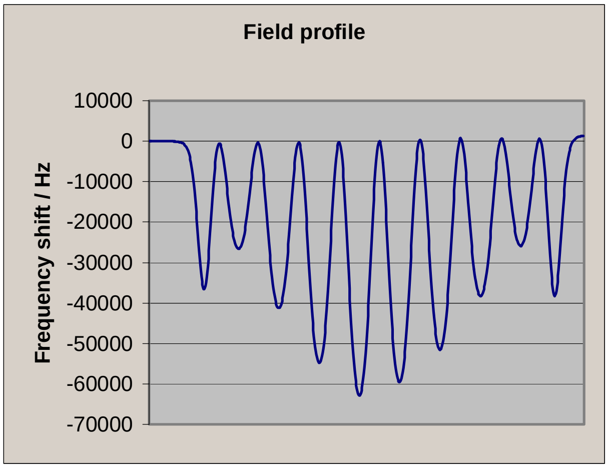


Fig. 7: Field profile of a copper 10-cell spoketype cavity

4 QWR FOR THE NEW COSY INJECTOR

In order to increase the intensity of polarised proton and deuteron beams a new pre-accelerator replacing the cyclotron JULIC will be build. Our aim was to find an optimum solution in terms of justifiable resources, available space, accessibility, minimum interference with the ongoing experimental program at COSY, as well as recent developments in the field of accelerators. As a result, the option of a superconducting LINAC was favoured [11].

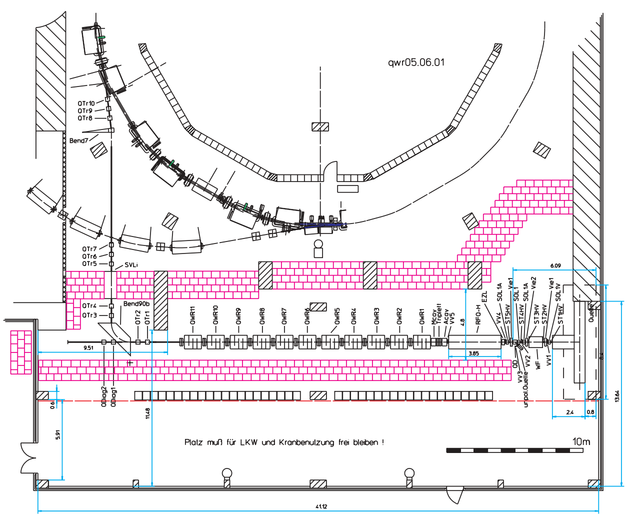


Fig. 8: COSY-LINAC Layout

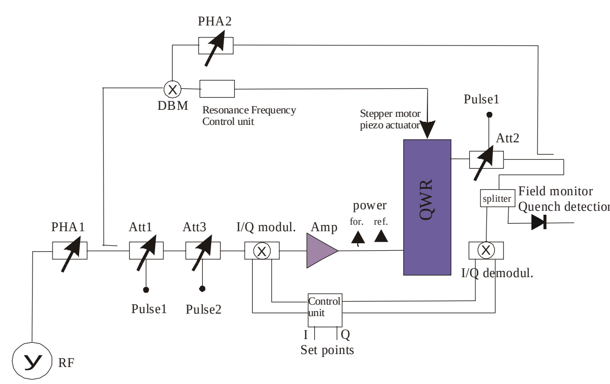
For the development of the Quarter Wave Resonators (QWR) we found an experienced partner, the LNL in Padova (Italy) where the ALPI heavy ion accelerator was designed and constructed [12]. Four QWRs are grouped in each cryostat such that the two central ones are oriented in the opposite direction of the two outer ones. This is necessary to compensate for the effect of transverse RF field components encountered by the beam during acceleration [13]. The basic parameters of the superconductive linac are summarized in the following table.

Table1: Basic parameters

Beam energy	2.5-50	MeV
Beam current	2	mA
Beam pulse duration	500	µs
Repetition rate	2	Hz
Number of QWR groups	3	
Number of total cavities	44	
Cavity temperature	4.2	K
Number of cryostats	11	
RF frequencies	160, 320	MHz
Accelerating field	~ 8	MV/m
Q_0 at E_{acc}	1E8	
Q_{ext}	~1E6	
Synchronous phase	-30	°
RF power per QWR	3	kW

A new vertical cryostat will be installed in the test area to perform test of the planned spoketype cavities, the QWRs used for a new LINAC and elliptical cavities at 4.5 and 2K. Separate top-flanges will allow an easy change of the different cavities.

The RF system of the test area needs only small changes. Additionally an analogue control system for amplitude and phase will be included based on I/Q-signals. The control unit can be modified by a digital processing [14] to benefit the more flexibility especially for a control of the beam energy from pulse to pulse



PHA1: Phase control of each cavity
Att1: Fast attenuator to switch from low level CW field to accelerating field
Att2: Complementary used attenuator to compensate the field probe level
Att3: Feed-forward for beam loading
DBM: Double balanced mixer
PHA2: Phase trim of resonance frequency control system
Pulse1: Pulse input to fill the cavity from low level CW field accelerating field
Pulse2: Feedfoward for beamloading

Fig: 9 QWR RF system

The QWRs will be analysed in a similar way as the ESS test cavity. Even a fast tuner will be installed for a fast resonance control in pulsed operation if necessarily.

.

REFERENCES

[1] G.Schug et al, Radiation Protection for ESS Prototype-Cavity Experiments, IKP Ann. Rep. 1998, Jül-3640

[2] ESS, A next Generation Neutron Source for Europe, Volume III, ESS-96-93-M

[3] H.Vogel et al, A Superconducting Accelerating Test Module for the European Spallation Neutron Source, PAC99, New York

[4] J.R. Alonso, The Spallation Neutron Source Projekt, PAC99, New York

[5] H. Haseroth, CERN Ideas and Plans for a Neutrino Factory, NuFact'00 Workshop, Monterey

[6] W. Diete et al, A Superconducting Accelerating Test Module for the European Spallation Neutron Source, PAC99, New York

[7] J.F. Stelzer, Analysis of the dynamic behaviour of the ESS superconducting accelerator modules, to be published as ESS Report

[8] C. Pagani, RFS Activities at INFN Milano-LASA, 7th workshop of superconductivity, Saclay

[9] C. Deutsch, Field-profile measurements at a 5-gap crossed-spokes model cavity, IKP Ann. Rep. 1999. Jül 3744, p. 181

[10] E.Zaplatin, Low-β SC RF Cavity Investigations, this workshop

[11] W.Bräutigam, SC Accelerator Components for Light Ion Linacs, this workshop

[12] A. Facco, Study on beam steering in intermediate-ß superconducting quarter wave resonatores, PAC 2001, Chicago

[13] Y.Senichev, private communication

[14] S. Simrock, Design of the digital RF control system for the TESLA TEST FACILITY, EAPC96, Barcelona