# RF SYSTEM OF COSY JÜLICH

G. Berg +), W. Bräutigam, H. U. Hacker, A. Hardt, H. Launer,
S. Martin, K. Nau, A. Richert, W. Spieß, G. Wüstefeld ++),
KFA Jülich, COSY, Postfach 1913, D-5170 Jülich


## Abstract

The RF manipulations in the cooler storage ring COSY will be done using the following systems:

An RF station will be working up to 200 kV at the extraction bunch-frequency of the injector cyclotron (27.7 MHz corresponding to a harmonic number of 60 in COSY for 40-MeV protons).Without a bunch rotation at h = 60 a dilution of the phase space of a factor of 5 will occur.

A ferrite tuned station will provide an accelerating RF voltage of 10 kV at the COSY revolution frequency 0.46 ... 1.57 MHz (h = 1).

Several beam-feed-back damper systems will counteract the longitudinal and transversal beam instabilities arising in the stochastically and electron cooled beam. Longitudinally smoothing the beam walls and RF shielding of beam-tube steps will be applied in addition.


## 1. Environment of the COSY RF system

The RF parameters of COSY [15] are influenced by the extraction parameters of the injector cyclotron **JULIC**, and the ramping procedure of the fields of the COSY bending magnets. A short list of the RF relevant COSY parameters is given in Table 1.

The RF cavities will be placed in the cooling-telescope beam-line in the almost dispersion-free section between the first and second quadrupol tripletts in the cooling-telescope beam-line as shown in [15.0]. There the COSY lattice is also described in more detail in [15.2].

Some examples of signal ways to be used for beam-feed-back dampers and stochastic cooling are drawn in the COSY scheme in [15.3].

The change of the parameters of the cavities, amplifiers, and regulation-circuits (resonant frequency, amplitude and phase of the RF voltage, amplification factor, detuning and damping), will be done via the local control systems. The operation modes will be chosen by the overall control system [15.4].

**Table 1**:
COSY parameters important for the RF system

| | | |
|---|---|---|
| COSY circumference | 183,5 | m |
| momentum of protons | 0,28 ... 3,2 | GeV/c |
| velocity of protons | 0,28 ... 0,96 | c |
| revolution frequency | 0,462 .. 1,572 | MHz |
| max. number of circul. protons | 3 * 10 | |
| max. circulating current | 23 ... 75 | mA |

---

+) now at IUCF, Bloomington;
++) now with BESSY, Berlin

## 2. The 27.7-MHz RF system at h_i = 60 in COSY

### 2.1. Scope of the the station

The first RF station will be working at a fixed frequency, namely at the extraction bunch-frequency f_i of JULIC (f_i = 27.7 MHz, h_i = 60 in COSY for 40-MeV protons).The 27.7-MHz part will be used

* for bunch-into-bucket injection from JULIC, an RF voltage of U_i ~= 200 kV will be applied to trap the injected beam having a momentum spread of Delta p / p = 0.2 % (half width),
* for compensation of the average beam-energy loss caused by the stripping foil during the injection,
* for compensation of the average energy loss caused by the internal target during in the recirculation mode, and
* for bunch rotation in order to preserve the longitudinal phase space of the injected beam. Otherwise, a dilution of the phase space of at least the factor of 5 will occur.

Some system parameters are shown in Table 2. The cavity will be de-enegized, detunend and damped during operation of the h=1 station in order to decrease the beam coupling impedances.

### 2.2. Technical arrangement of the 27.7-MHz station

The 27.7-MHz station will consist of a folded-transmission-line resonator scaled from the AC 9.55-MHz bunch-rotator cavity [1] and a modified short-wave transmitter amplifier.

**Table 2**:
Parameters of the COSY RF station I

| | | |
|---|---|---|
| momentum of protons | 0,28 | GeV/c |
| JULIC extraction frequency | 27,7 | MHz |
| revolution frequency of COSY | 0,462 | MHz |
| harmonic number of COSY | 60 | |
| synchr. phase f. bunch-into-bucket injection via stripping foil | ca. 0,1 | ° |
| momentum spread after debunching | 4 * | E-4 |
| for momentum spread at injection | 20 * | E-4 |
| longitud. phase-space volume | 0,14 | eVs |
| RF peak voltage at max. duty cycle of 10 % , max. switch-on time of 10 ms | 200 | kV |
| unloaded quality factor | 5 * | E+3 |
| average-power capability | 100 | kW |
| impulse-power capability | 10 | kW |

## 3. The accelerating station at h = 1 in COSY

### 3.1. Longitudinal beam dynamics of the station

The h=1 cavity working at 0.46 to 1.6 MHz adiabatically traps and accelerates the particles in COSY up to the final energy.

The number h=1 is chosen because of reasons concerning the longitudinal acceptance, the time clearance for rising an extraction kicker, and the RF-induced heat dissipation in the ferrite rings.

The trapping and acceleration processes are described in Fig. 1 for protons injected having a momentum spread of $\Delta p / p = 0.2$ % (half width). This corresponds to a longitudinal phase space area of 0.7 eVs. The RF voltage and phase will be set to the values also shown in Fig. 1. We get the time of Step I as $t_c = 5$ ms for a choice of the adiabatic parameter [2] $\alpha_c = 0.25$ and a synchrotron frequency $1/T_s = 580$ Hz at the end of Step I. The cavity voltage $U_c$ vs. the time t results from the above adiabatic condition :

$$U_c(t) = U_0 / (1 - \alpha_c \cdot t / T_s)^{2},$$

$$U_0 = 100 \text{ V}, \quad 0 \le t \le t_c .$$

The voltage and phase are set to

$$U_c = 5 \text{ kV} \quad \text{and} \quad \Phi_{s\_c} = 15\,^\circ .$$

During the acceleration process (Step III) for the given end value of the bending-field ramp rate. This leads to a phase-space area of $A_1 = 0.94$ eVs which incloses the bunch area with sufficient clearance [3]. The RF parameters will also be changed adibatically during Step II.

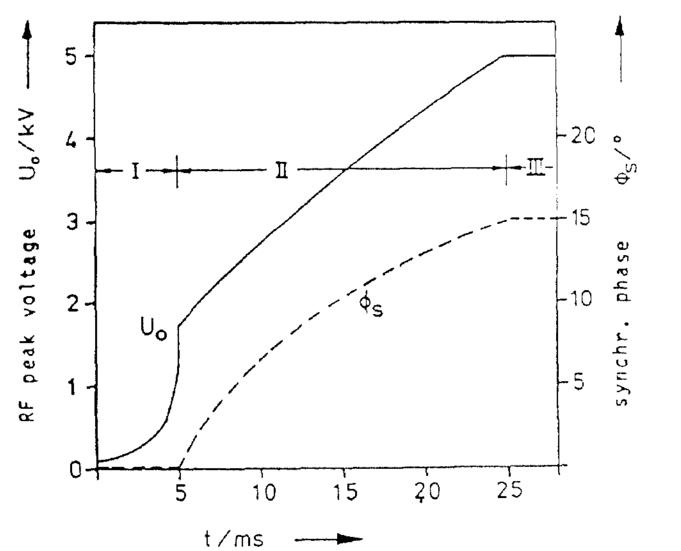


**Figure 1** :
*Amplitude & phase of the h=1 accelerating voltage The trapping and acceleration processes are calculated for protons injected with a momentum spread of $\Delta p / p = 0.2$ % (half width). The ratio of bunch and bucket phase-space area is set to 70 %. The adiabatic parameter is set to $\alpha_c = 0.25$; Transition: $\gamma_{tr} = 2.39$, $T_{tr} = 1.3$ GeV.*

I adiabatic trapping of protons,
II preparation of the bending-field rate of 1 T/s,
III acceleration with 1.28 keV per turn at 1 T/s.

Some design parameters are listed in Table 3. COSY will cross the transition energy which moderates the required RF voltage but increases the stability problems.

The design value of the circulating particles for calculation of the power bilance is set to 3.E11 according to the limiting case [4]. The current limits arising from coherent beam self fields are still under contemplation.

**Table 3**:
Beam-relevant parameters of the COSY RF station II (h = 1)

| | | |
|---|---|---|
| harmonic number | 1 | |
| energy gain per turn | 1,28 | keV |
| operating frequency | 0,462 .. 1,572 | MHz |
| RF accelerating voltage | 5 | kV |
| accelerating synchr. phase angle | + 15 | ° |
| longitudinal input acceptance | 1 | eVs |
| at transition relativistic parameter | 2,39 | |
| max. RF bunching voltage | 10 | kV |
| input momentum spread (half width) | 3 | E-3 |

### 3.2. Technical arrangement of the h=1 station

The h=1 station will consist of a 0.4-to-2-MHz amplifier feeding the ferrite-tuned resonating circuit that provides the accelerating voltage. The usage of only one h=1 station provides advantages concerning the space requirements, manufacturing and control-system expenses, and beam coupling impedances at higher harmonic frequencies.

The accelerating structure is similar to that used in most of the low- and medium-energy proton and heavy-ion rings with low-harmonic-number RF systems. It consists of a re-entrant coaxial cavity partially ferrite filled and the gap shunted by 8 vacuum condensers working in parallel. The total gap capacity has a value of 2 nF a propriate to the resonance in the operating frequency range. The structure is tuned to the accelerating frequency via the parallel bias magnetic field generated by the 1-turn coil. Most of the const uctive details are taken from the CERN LEAR [5]. Some characteristic data is listed in Table 4.

**Table 4**:
Technical data of the COSY RF station II (h = 1)

| | | |
|---|---|---|
| peak RF gap-voltage at max. duty cycle of 60 %, max. switch-on time of 10 s | 8 | kV |
| frequency range | 0,45 ... 1,8 | MHz |
| averaged RF power | 30 | kW |
| capacity for resonance | 1,86 | nF |
| max. B * f product | 14 | kHzT |
| total ferrite length | 1150 | mm |
| number of 25-mm ferrite rings | 46 | |
| ferrite innerers 300 498 | | mm |
| eff. permeability | 510 ... 43 | |
| magnetization bias current | 20 ... 600 | A |
| max. averaged ferrite power-loss density | 0,25 | MW/m**3 |
| max. averaged loss per 25-mm ferrite ring | 400 | W |

The ferrite rings are indirectly water-cooled using copper disks having cooling channels as used in most of the resonators of low-harmonic-number F systems. The water cooling yields lower mechanical stresses arising from the temperature gradients compared to air-cooled systems. The calculation of the thermal stresses within the ferrite rings showed a safety margin of 2 even for a high-power pulsed operation.

The RF and loss-power characteristics of the cavity are calculated including the influence of the inhomogenous bias and RF H-field distributions and the cooling irises using a program "SynRes". The ferrite data is taken from [6] - [8].

A test equipment for the RF acceleration structure is being built in order to investigate mechanical, thermal, and machining items.

## 4. A few aspects of coherent beam stability

If the electron- or stochastic-cooling system in COSY is switched on, the beam will get an equilibrium emittance caused by the cooling rate, the instability-growth rates an the intra-beam scattering.

A first guess of the beam-coupling-impedance values in COSY has shown that the transversal microwave instability will give a lower limit to the momentum spread (Keil-Zotter criterion [14]).

The following computer programs are in use to look for beam quality restrictions in COSY :

- URMEL, TBCI [9] and SUPERFISH [10] for calculation of the longitudinal or transverse impedance values of the beam surroundings.
- BBI [11] and ZAP [12] for checking the instabilities.

The Robinson criterion (s. e.g. [13],p.165) shows that there is no beam-current restriction because the beam-loading factor in the COSY RF system has a value of less than 1 %.

Some counter-measures reducing the longitudinal and transverse coherent instabilities will be taken into account in COSY (reduction of small-band broad-band and complex resistive-wall impedances):

* detuning and attenuation of cavity-like resonances,
* RF-shielding and attenuating inserts for the beam-line components like flange connections, pumping holes, bellows, target chambers,
* smoothing the beam-tube diameter steps by tapered sections having angles lower than 15 °,
* decrease of the surface roughness by electrochemical or erosive polishing,
* improvement of the conductivity of the inner surface of the beam tube using vapor or sputter deposition of a high-conductive sheath (an factor of 10 seems to be possible),
* reducing the apparent system-beam coupling impedances by means of beam feed-back systems.

Examples of RF shielding measures in COSY are shown in [15.5].

## 5. Acknowledgements

The authors are greatly indepted to Mr H. Henke (CERN-LEP) and Mr H.G. Hereward for their advice in the RF theory; Mr A. Susini, J. Jamsek, W. Groebli and C. Zettler (CERN-PS) for giving us comprehensive information about the CERN RF systems, Mr K. Kaspar and A. Gasper (GSI) for the comprehensive information about ferrites and ferrite cavities; Mr L. Palumbo (Univ. Roma) and V.G. Vaccaro (Univ. Napoli) for their advice in the theory of beam instabilities; Mrs K. Meyer for her programming work; Mr Butzek (KFA Jülich, ZAT) for his help in calculation of thermal stresses of ferrites, Mr D. Rosin, F. Helk, D. Hein and G. Siekmeyer for their aid in construction and installation of the test bench, Mr W. Wilms (KFA Jülich, IKP) for persuing thermal measurements; Mr K. Döring, Ph.-J. Kieven, H. Klär, T. Liesen, H. Stechemesser, and A. Zumloh (KFA Jülich, ZAT) for the mechanical design of the beam-line elements.

## 6. References

[1] The 9.6-MHz system on the authority of W. Pirkl, CERN, is briefly described in E. J. N. Wilson (Ed.), "Design Study of an Antiproton Collector for the Antiproton Accumulator (ACOL)", CERN 83-10, pp.13...19.

[2] Boussard, D., "RF techniques for p $\bar{p}$ ", CAS Antip. Coll. B. Fac., CERN 84-15, pp. 261...90.

[3] Hereward, H.G., Private communication, KFA Jülich 1986.

[4] Bovet, C., Gouiran, R., Gumowski, I., Reich, K.H., "A selection of formulae and data useful for the design of A. G. synchrotrons", CERN/MPS-SI/Int. DL/70/4 [23.Apr.70, Repr. 25.4.80]; Results for COSY: G. Wüstefeld, COSY-Note 72 [Jan.1987].

[5] Plass,G. (Ed.), "Design study of a facility for experiments with low energy antiprotons (LEAR)", CERN/PS/DL 80-7 [16.5.80]; Groebli,W., Jamsek, J., Susini,A., Private communication, CERN 1986.

[6] Bendall, R.G., Church,R.A., " Ferrite measurements for SNS accelerating cavities", SNS/Phi/N2/79, RL-79-024 [RAL, Mar.1979].

[7] Kaspar, M., Emmerling, M., Gasper, A., "Measurements on the ferrite ring for the SIS prototype cavity", GSI Sci. Re . 1980, GSI 81-2, p. 256; Kaspar, M., Emmerling, M., "Development of the RF acceleration system for the GSI heavy ion synchrotron", IEEE Trans. NS-28,3 [Jun.1981], 3004...6.

[8] Philips Elcoma Materials Co., " A selection guide of materials for particle accelerators 1983/84"; "myQ products in remanence (typical values of recent products)", [Eindhoven, 11.Jan.1988].

[9] Weiland,T.,"TBCI and URMEL, new computer codes for wake field and cavity mode calculations",DESY M-83-08 [Mar.83]

[10] Halbach,K., Holsinger,R.F., "SUPERFISH - a computer program for evaluation of RF cavities with cylindrical symmetry", Part. Acc. 7 [1976], pp. 213...222.

[11] Gygi-Hanney, M., Hofmann, A., Hübner, K., Zotter, B., "Program BBI: Bunched Beam Insta- bilities in high energy storage rings", CERN/LEP-TH/83-2 [Jan.1983].

[12] Zisman,Michael S., Chattopadhyay,Swapan, Bisognano, Joseph J.,"ZAP User's Manual",LBL-21270, ESG-15 [Dec.1986].

[13] Hofmann,A.,"Single-beam collective phenomena - longitudinal",C. Int. Sch. Part. Acc. 1, CERN 77-13, pp. 139...174

[14] Schnell,W., Zotter,B.,"A simplified criterion for transverse stability of a coasting beam and its application to the ISR", CERN-ISR-GS-RF/76-26 [Jul.76]

[15] **COSY-Jülich Contributions to these proceedings:** 0) U. Pfister and the COSY Team, "Status of COSY Jülich", LS05 and LP104; 1) W. Bräutigam, et al., "Upgrading JULIC as injector for COSY", LP164; 2) P. Krejcik et al., "COSY-lattice description", KP135; 3) N. Bongers et al., "First considerations on stochastic cooling in COSY", MP152; 4) N. Bongers, et al., "Expert system for COSY control", NP173; 5) Stechemesser,H. et al., "Design and technical features of the vacuum system at COSY", KP008.