THE NEW PHASE DETECTION SYSTEM OF THE COSY-INJECTOR

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ABSTRACT

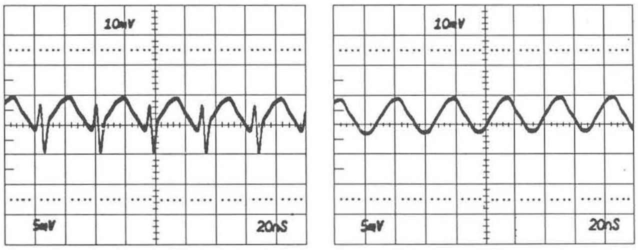
For the Julic isochronous cyclotron JULIC a new beam phase detection system has been developed on the basis of the heterodyne principle using rf-signal mixing and filtering, rf-disturbance compensating techniques and 50Ω striplines, similar to the old phase measuring equipment (set to work in 1978). The new equipment detects and analyses the beam signals within a beam current range of 20nA to 50μA with satisfying accuracy. In addition to the old phase measuring system the new one is controlled by computer and able to determine the beam phase angle and beam intensity for continuous and pulsed beams (down to approx. 5msec beam on). Furthermore the new equipment includes a facility for calibrating the total beam phase detection system by a rf-signal decoupled from a dee. Testbench measurements, showing the linearity over the full dynamic range, as well as measurements with beam are presented.

1. INTRODUCTION

The cyclotron JULIC is undergoing extensive upgrading in order to serve as injector for the new Cooler synchrotron COSY-Jülich.[1)2)] Part of the upgrading is the installation of the new **PHAS**e **M**easuring **E**quipment PHASME II. The upgrading of the existing PHASME I[3)] was necessary to get a much faster handling of the measured beam signals and especially to measure the phase in a pulsed beam mode needed for injection into the COSY-ring. The phase detection system should work over the full cyclotron frequency range from 20 to 30Mhz. The accuracy should be better than $\pm 1^0$ over the total dynamic range. In order to get an automatic noise voltage suppression a compensating unit is installed. The detection system is able to handle internal beam currents from 20nA to 50μA.

2. LAYOUT OF THE PHASE DETECTION SYSTEM

The beam signals are decoupled by 24 probes mounted above and below the medium plane of the cyclotron. The probes are 50Ω striplines where the upstream end is open. The length of each probe is 15cm, the width 15mm and the distance between the upper and lower probes is 20 mm.[3)] Together with the beam signals disturbing rf-voltages from the acceleration system are picked up. The noise comes from the accelerating rf-voltage, about 45 kV when JULIC is operated at maximum energy, resulting in a noise amplitude of about 10 mV at the pickup output. The disturbances can be much greater than the beam signals. As they are opposite in phase and almost equal in amplitude, the addition of the upper and lower probe signals is a first step to reduce these voltages. Since on the other hand the beam signals are equal in phase on the corresponding probes, their output is simultaneously doubled. Figure 1 shows the output voltage for one probe pair with and without beam.



with beam without beam

Fig. 1. measured signal of pickup pair 6

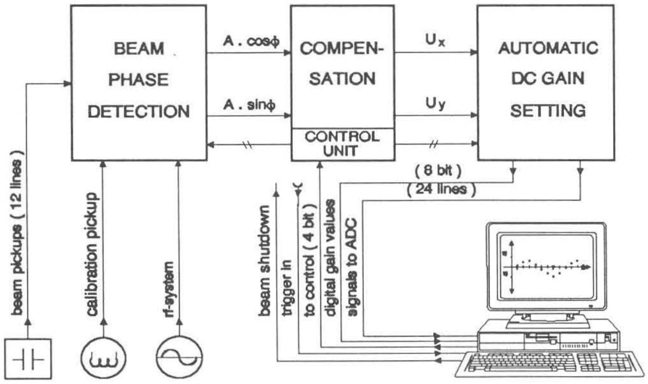


Fig. 2. schematic of PHASME II

Even if the beam signal to rf-disturbance ratio on the average is better for higher harmonics, we decided to work on the 2nd harmonic for the following reason: As

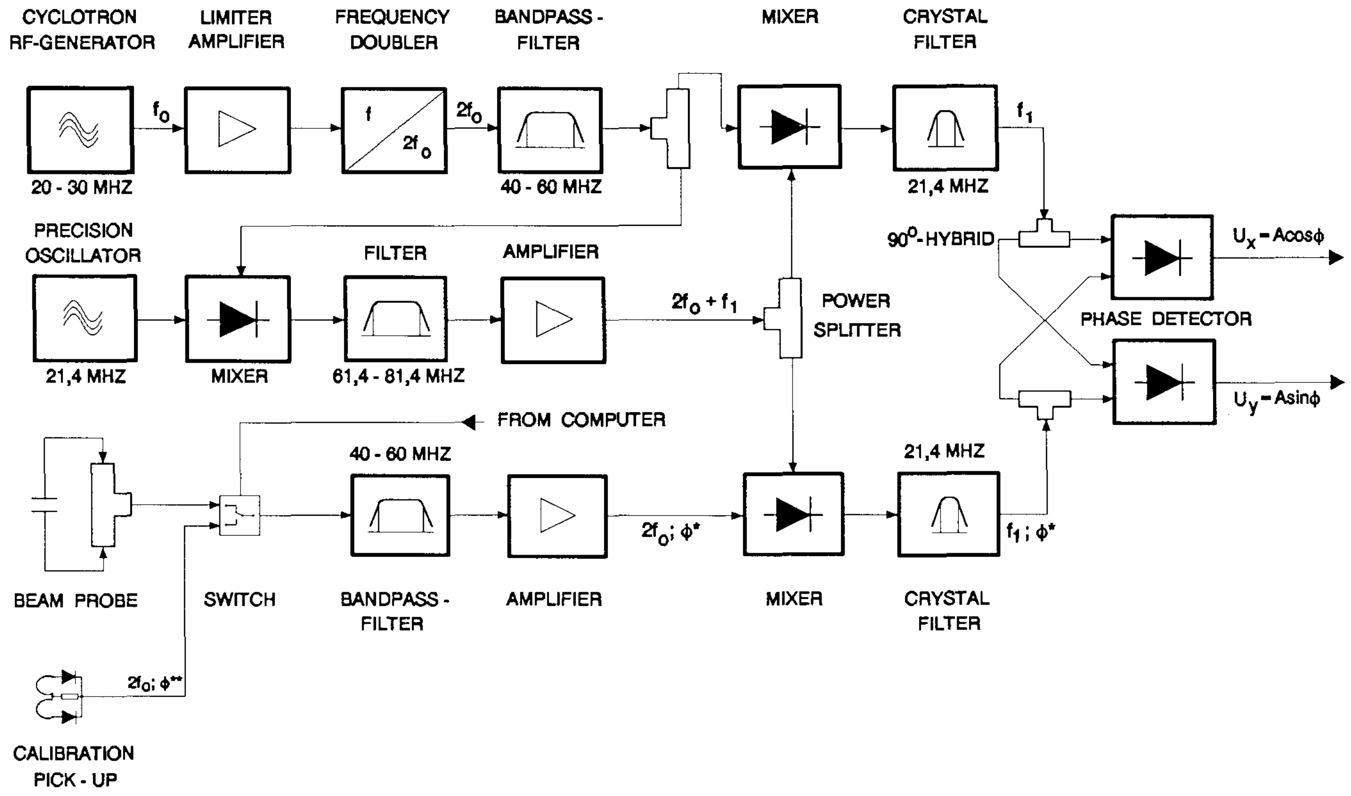


Fig. 3. blockdiagram of the rf-part

the measured phase angle of the beam is multiplied by the harmonic number, the possible range of $-90^{0} < \varphi_{\mathrm{beam}} > +90^{0}$ is converted to $-180^{0} < \varphi > +180^{0}$ which can be detected directly without ambiguity.

Figure 2 shows a schematic of PHASME II. The major subsystems are the "beam phase detection", "the compensation" including the "control unit", the "automatic DC gain setting" as well as a PC. In order to get phase information along the cyclotron radius, 12 independent pickup pairs are used together with 12 parallel operating phase detection channels. After adequate amplification the 24 DC-signals - X-Y-components of 12 phase vectors - are fed to two ADC's in the PC. Likewise the corresponding digital gain values are fed to the PC. The PC drives the central control unit, digitizes, calculates and displays the measured beam phase signals and angles of the 12 pickups along the cyclotron radius. By a trigger signal from the central clock of the COSY-ring the PC and PHASME II are synchronized to the pulsed beam. Compared to the old system PHASME I[3] all 12 channels can be read out in parallel without channel multiplexing. Thus the beam phase can be measured in continuous as well as in pulsed beam mode. The shortest pulse width is approx. 5msec. An extra pickup mounted in the dee provides the possibility to eliminate phase response differences between the 12 rf-signal handling channels and a method for calibrating the system to the beam zero phase. PHASME II works over the full cyclotron frequency range.

The rf-circuit design was based on commercially available rf-components as power splitters, double balanced mixers, frequency doublers, hybrids, crystal filters, amplifiers and GaAsFet-switches. Bandpass filters and amplifiers for signal and impedance matching were developed in our laboratory. The internal rf-connections and the thirteen 33m long pickup lines are realized in form of semi-rigid coaxial cables. The whole PHASME II has been built into the mechanical system EUROPACK.

2.1 Details of the RF-part

Like in the old PHASME I also in PHASME II we make use of the heterodyne principle, which in the past already allowed a precise and reliable beam phase detection (Fig. 3). Just as for PHASME I we use the two DC-output signals of the phase detectors, which are components of a vector in rectangular coordinates, to determine the phase angles and the beam intensity. This vector still has an inherent error, which is induced by the 2nd harmonic content of the accelerating voltage in the pickup signals and by a small DC-offset voltage of the phase detector outputs themselves. This error will be compensated when the beam is switched off.

The basic rf-signal handling of PHASME II already has been described earlier.[3)] In order to avoid a frequency synthesizer[3)] we insert an additional frequency mixing stage and choose an intermediate fixed frequency of $f_1 =$ 21.4Mhz. By this frequency conversion the required signal $2f_0 + f_1$ is generated with the output signal of a 21.4Mhz fixed frequency oscillator and a $2f_0$ signal derived from the reference channel.

The GaAsFet-switch in the information channel input allows to connect the following bandpass filter either with the beam signal or the output signal of the calibration pickup.

The phase detection is similar to that of PHASME I, but the needed 90^0-phase shift now has been realized by hybrids, which are commercially available. Both DC-signals of the phase detectors are amplified by a factor of about 100, so that for internal beam currents of 50μA the DC-signals are nearly 10V.

By the calibration pickup, mounted in the cyclotron dee, a signal is decoupled from the rf-system, then doubled in frequency and simultaneously fed to the 12 switches in the information channels. There the probe signals can be replaced by the signal, derived from the calibration pickup. The cables are in both cases equal in electrical length. So a frequency independent phase response test of the information channels is possible. Without beam the phase behavior can be measured by PHASME II and taken into account for the calculation of the beam phase angles. Because the output voltage of the calibration pickup in the dee has a constant, frequency independent phase offset to the accelerating voltage, we use this feature for calibration.

2.2 The Readout Electronics

The inherent error of the 24 phase detector output signals will be compensated by the "compensation" of PHASME II (Fig. 2) a few msec before the beam is switched on. This section mainly contains 24 parallel operating analog auto-zeroing circuits modified for our application. All circuits and also the following 24 DC-amplifiers are activated synchronously by the control unit and the PC.

In order to cover the dynamic range of the rf-section and to be free from gain setting by the PC the 24 DC-signals of the X-Y-vector components now are amplified by the "automatic DC gain setting" which consists of 12 pairs of X- and Y-autoranging amplifier stages. Their amplification factors can be automatically set from 1 to 4096 in steps of 1, 4, 16, ... To get sufficient accuracy for the data conversion, the DC-signals are amplified in such a way that always voltages between ±2.5V and ±10V will be fed to the 12bit ADC's in the PC. Parallel to this the gain steps, 4bit data words, are transmitted to the PC, where they are used for the calculation of the phase angles as well as the intensity of the internal beam.

3. RESULTS OF THE TESTBENCH

Due to the width of 15mm the pickups take depending on radius position signals from about 2 to 9 beam orbits. This results in a measured sensitivity of about 100μV/μA (DC beam current).[3)] The allowed 2nd harmonic beam signal voltages must lie in the range from 2μV to 5mV. That means, with PHASME II we can detect beam currents from 20nA to 50μA.

In order to measure the linearity of the rf-part within the dynamic range, we fed two rf-signals to PHASME II, one to the f_0 input with the cyclotron frequency $f_0 =$ 25Mhz and an amplitude of 250mV, the other to a probe input as a 2nd harmonic probe signal $2f_0$ but with a frequency lag of 1kHz and variable amplitude. In Fig. 4a the beam amplitude was adjusted in such a way that on a X-Y-scope the two output signals of the corresponding phase detector form a circle. In Fig. 4b-4d the beam signal was reduced by a factor of 10 from picture to picture. It is obvious from the circles that PHASME II works very well within a dynamic range of 60db with sufficient amplitude linearity. For the given amplification of the rf-part of nearly 3000 (a factor of about 30 for the information channels and about 100 for the DC-output signals of the phase detectors) the 10mV output signal is due to an 2nd harmonic probe signal voltage of about 3.5μV.

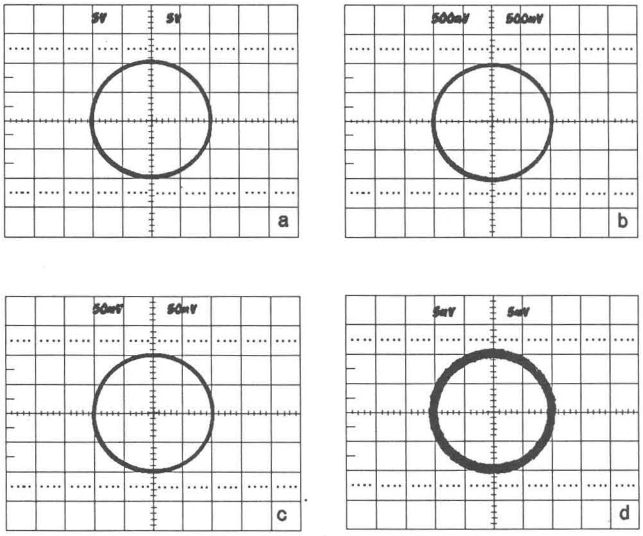


Fig. 4. amplitude linearity (f_0 = 25Mhz)

In Tab. 1 the output phase is shown for different input signals varying in amplitude and phase. The cyclotron test frequency f_0 is 27.316Mhz. The output phase was measured with the complete system, including the numeric data handling of the PC. For an input signal of about 3μV the phase accuracy is $\pm 0.5^0$, whereas for the maximum allowed input signal the accuracy is ±0.25^0. As appears from Tab. 1 the phase reading follows precisely the input phase. Please note, that without 2nd harmonic disturbances the phase detector outputs of their own have an DC-offset in the range of ±0.2mV to ±0.5mV. Comparing this offset to the amplified signals of about 5mV to 10mV for the lowest input signals and regarding to the mentioned phase accuracy the compensation must work sufficiently. For Fig. 4 and Tab. 1 two different frequencies were chosen in order to demonstrate the frequency variability of PHASME II.

Tab. 1. phase linearity of PHASME II

$\phi_o[...^o]$ $\phi_{in}[...^o]$	$U_{in}(2f_o)$ 3620μV (-36dbm)	$U_{in}(2f_o)$ 362μV (-56dbm)	$U_{in}(2f_o)$ 36,2μV (-76dbm)	$U_{in}(2f_o)$ 3,62μV (-96dbm)	accuracy within 60dbm
0	172,95	173,05	172,75	172,40	± 0,39
30	143,21	143,20	142,69	142,90	± 0,31
60	112,62	113,05	112,82	112,70	± 0,25
90	82,72	82,70	82,8	83,05	± 0,23
120	53,05	53,05	52,92	53,10	± 0,12
150	22,80	22,85	22,60	22,90	± 0,19
180	-7,19	-7,35	-7,08	-7,32	± 0,15
accuracy within 180°	± 0,26	± 0,29	± 0,19	± 0,41	average deviation [...°]

ϕ_{in} - input phase; $\phi_o[...^o]$ - measured output phase;

$U_{in}(2f_o)$ - second harmanic input voltage ; test frequency f_o - 27,316Mhz

4. TEST WITH BEAM

For a first test PHASME II was connected to the 12 probe pairs in the cyclotron.

In Fig. 1 the signals from probe pair 6 are shown on an oscilloscope with and without beam for an internal cyclotron beam of about 6μA.

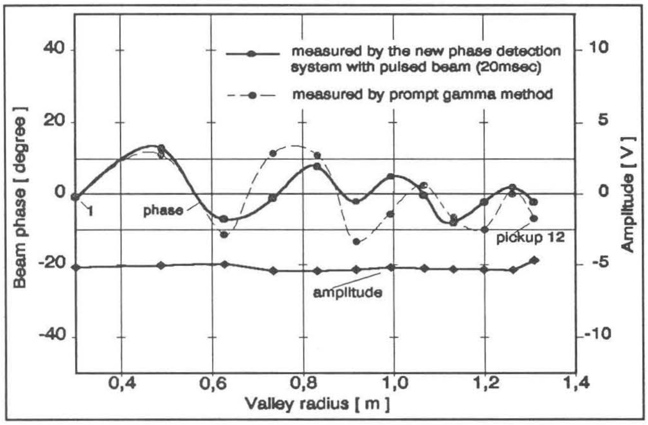


Fig. 5. measurement with beam

In Fig. 5 the amplitude of the beam phase vector, representing the beam intensity, and the beam phase are shown along the different probe positions for an internal pulsed cyclotron beam of about 15μA. The pulse length was 20msec with a repetition rate of 2 Hz. The phase information is compared with an independent beam disturbing phase measurement done by prompt gamma rays. The agreement of both curves is obvious and acceptable for a first test. The amplitude is nearly constant over the 12 probes, although the number of beam orbits and the beam energy is varying along the radius, from the inner pickup (r = 0.3m) to the outer one (r = 1.53m) by a factor of about 26 (from 1.45 MeV/a to 38MeV/a).

The cyclotrons operating parameters for both measurements are: U_{rf}= 35kV, f_0= 27.316Mhz, 76MeV H_2^+, external beam current about 8μA.

5. POSSIBLE FUTURE OUTLOOK

Due to the broadband properties of the probes the analysed signals in the time domain can give information about the bunch shape. Therefore the rf-noise signal must be known in amplitude and phase. The bunch shape then can be elaborated by reconstruction methods.$^{4)}$

With PHASME II we get the 2nd harmonic beam signal, which is related to the beam current. If it should be possible to measure simultaneously the sum and difference of the upper and lower pickup signals in spite of severe rf-interference with the accelerating voltage, there is in principle a possibility to detect vertical beam positions.

6. ACKNOWLEDGEMENT

The authors thank K. Bongardt for many fruitful discussions about pickup properties and especially about further options with PHASME II.

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