A MULTI-INPUT PHASE MEASURING SYSTEM

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Abstract

A multi-input phase measuring system is described which has been designed for the cyclotrons of HMI (Berlin) and EUT (Eindhoven). The phase probe signals are multiplexed to avoid phase differences between the various input channels.

After the input multiplexer the signals are transformed to a fixed frequency. Therefore the system needs no adjustment for different acceleration frequencies (i.e. particle energies). Test signals well below 1 μV can be measured with an accuracy of 0,1°, which is a characteristic of the phase measuring system. In the Eindhoven AVF cyclotron practical values for the lowest beam currents are about 15 nA for 3 MeV protons, due to signal disturbances of the cyclotron itself.

1. Introduction

The HF-phase of accelerated particles in cyclotrons can be measured non-destructively with capacitive pick-up probes. In the past a lot of work has been done at various laboratories concerning the design of the phase probes and the necessary electronic equipment (e.g. KFA-Jülich, KVI-Groningen, MSU-Michigan, EUT-Eindhoven). The sensitivity has increased from a few μA's to only a few nA's and the accuracy has increased from about 10° to less than 0.5°. Especially now the phase-measuring systems have proven there value, much attention is being paid to the reliability and the simplicity of operational procedures.

The phase-measuring systems can also be used to determine the energy of the particles in the external beam: e.g. two sets of non-intercepting phase probes are mounted in the external beam guiding system of the EUT cyclotron, about 13 m apart. The measured "phase difference" between the particles at both probes is interpreted as a "time-of-flight" and thus yields the energy of those particles. An accuracy of about 5.10^{-4} has been reached for a beam of 100 nA and a phase width of 6° (ref. 1).

Finally, the phase-probes in the beam guiding system can be used to determine non-destructively the position (better than 0.2 mm) and the intensity of the external beam (ref. 2). Especially the intensity is important for the extraction efficiency optimization (ref. 3).

We describe here the phase measuring systems develloped at EUT for the VICKSI-cyclotron at HMI and the EUT-cyclotron. The system of VICKSI is built by Scanditronix. This article deals with the principles of both systems and does not go into details.

2. The measuring equipment

Each phase probe in the cyclotron consists of two copper plates, one above and one below the median plane. The probes are individually shielded, and they are all mounted on a common shielded support. Triaxial cables (all with the same length !) bring the probe signals outside the cyclotron to a fast HF-multiplexer (16 channels, about 20 μs switching time).

The phase probes in the beam guiding system consist of 4 stripline-type pick-up plates (50 ohm impedance). The signals of the strip lines are brought outside individually and can be connected via amplifiers (27 db gain) to the HF-multiplexer or can be combined first with a combiner and then fed to the multiplexer. The HF-multiplexer followed by an amplifier, giving an overall gain of 40 db, is located below the cyclotron yoke.

The electronic equipment for signal processing is located in the cyclotron control room, about 50 m away. The equipment consists of the following parts:

- A signal conditioning section
- A special HF-mixer system to transform all relevant signals with a variable frequency to signals with a fixed frequency.
- A correlation section which correlates the phase probe signals with a reference signal derived from the acceleration voltage.
- A low-pass filter section after which the desired phase and amplitude information is obtained.
- A CAMAC system controlling the HF-multiplexer and performing the interface between analogue signals and the computer.
- A simple vector-display for visualization of the measured phase and amplitude.

2.1. The correlation section

The HF-phase and amplitude of the phase probe signals with respect to the acceleration voltage, are determined with a simple correlator (see fig. 1).

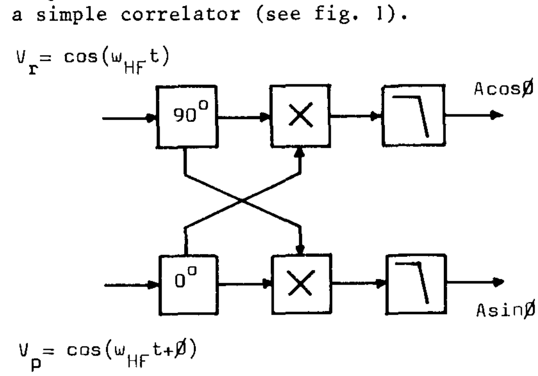

Fig. 1: *Block scheme of the correlator*

The phase probe signal $V_p = \cos(\omega_{HF}t + \phi)$ is multiplied with two reference signals $V_r = \cos(\omega_{HF}t)$ of equal amplitude and frequency but shifted over 90° in phase with respect to each other. The two DC signals obtained after the low-pass filters are proportional to $A\cos(\phi)$ and $A\sin(\phi)$.

The problems of this simple type of correlator arise from the 90° phase shifter. Due to the variable frequency of the acceleration voltage, often more than one octave, no accurate 90° phase shifters are available. This problem can be solved in various ways:

1) A variable cable delay can be used as phase shifter
2) Via a sampling technique with a variable sampling rate the HF-signals with variable frequency can be transformed into LF-signals with a fixed frequency. Then an accurate 90° phase shifter can be realized (ref. 2).
3) Via a special mixing technique the HF-signals with variable frequencies can be automatically transformed into HF-signals with a fixed frequency . In this case a fixed cable delay can be used as 90° phase shifter.

Methods 1) and 2) require manual tuning which is a serious drawback. Method 2) has moreover the serious disadvantage that the sampling process produces extra noise. Further, the HF-signals are only sampled for a small percentage of time leading to long correlation times (> 1 sec). Method 3) does not need manual tuning and has short correlation times (< 1 msec).

2.2. The mixing section

The special mixing technique (method 3)) as mentioned in the previous section is described below (ref.4,5). A block diagram is given in fig. 2.

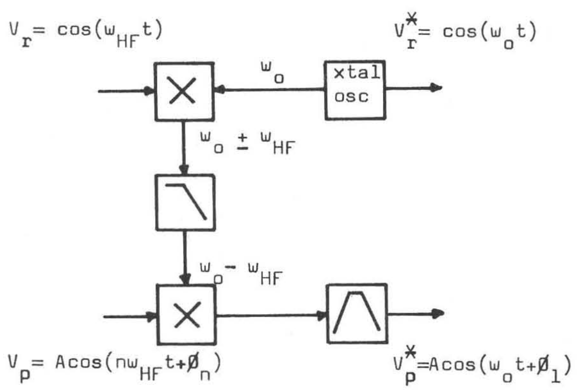

Fig. 2: *Block schema of the mixing section.*

The aim of the mixer is to transform all relevant input signals with variable frequency into output signals with a fixed, crystal-controlled frequency. The output signals are then fed to the correlation unit.

The reference signal $V_r = \cos(\omega_{HF}t)$, derived from the acceleration voltage, is multiplied with a second reference signal $V_r^* = \cos(\omega_o t)$, derived from a crystal controlled oscillator. This results in two signals with frequencies $\omega_o - \omega_{HF}$ and $\omega_o + \omega_{HF}$. After a sharp low-pass filter we obtain a signal with a frequency of $\omega_o - \omega_{HF}$.

This signal is then multiplied with the phase probe signal $V_p = \cos(n\omega_{HF}t + \phi_n)$, where n is the harmonic number. The resulting signals have frequencies of $\omega_o - \omega_{HF} + n\omega_{HF}$ and $\omega_o - \omega_{HF} - n\omega_{HF}$. Applying a very sharp and stable band pass filter at ω_o, we only let through a signal with the fixed frequency ω_o and with a phase of ϕ_1 with respect to the reference signal: $V_i = \cos(\omega_o t + \phi_1)$.

Summarizing: The phase probe signal $V_p = \cos(n\omega_{HF}t + \phi_n)$ is transformed into $V_p^* = \cos(\omega_o t + \phi_1)$. $V_r^* = \cos(\omega_o t)$ is used as the new reference signal. These two signals can be handled by the correlator, as described in section 2.1, with a fixed cable delay 90° phase shifter.

REMARK

The mixer as described above selects one harmonic out of the phase probe signal (the first harmonic in this example). If the reference signal is doubled in its frequency $V_r = \cos 2\omega_{HF}t)$ the second harmonic out of the phase probe signal will be selected. This is actually done because the disturbing signals on the second harmonic are about 20 db lower than on the fundamental harmonic.

2.3 Signal conditioning

The phase probe signals contain a lot of higher harmonics of the acceleration frequency ω_{HF}. As we are only using the second harmonic, the higher harmonics are filtered by a sharp low-pass filter.

Under certain conditions this low pass filter is even essential! In the mixer section a signal with a frequency of $\omega_o - 2\omega_{HF}$ is mixed with the probe signal having frequencies of $n\omega_{HF}$, resulting in frequencies of: $\omega_i = \omega_o - 2\omega_{HF} \pm n\omega_{HF}$. Only signals with $\omega_i = \omega_o$ (i.e. $n = 2$) pass the narrow band-pass filter. However, also signals with frequencies of $\omega_i = -\omega_o$ (i.e. with frequency of ω_o shifted over 180°) pass the narrow band-pass filter:
$\omega_i = -(\omega_o - 2\omega_{HF} + n\omega_{HF})$.
If ω_{HF} is a submultiple of ω_o ($\omega_{HF} = \omega_o/N$) it follows that: $n = 2N - 2$ i.e. the $(2N - 2)$ th harmonic will also pass the band pass filter!. Because of this beating phenomena unpredictable results occur. In fig. 3 this condition is given schematically.

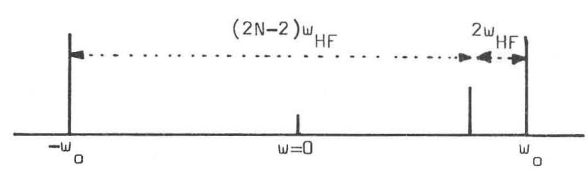

Fig. 3: *A schematic representation of the beating phenomena.*

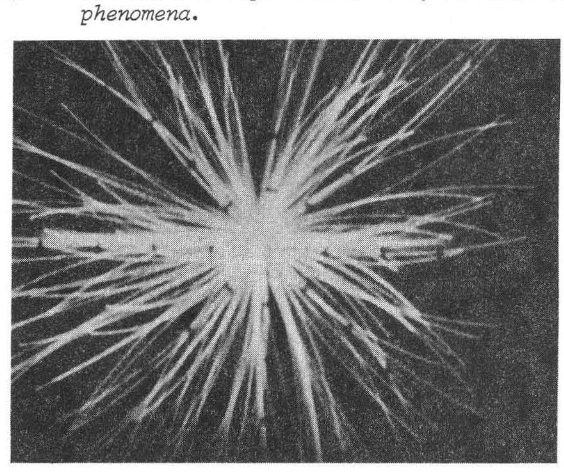

Fig. 4. *The beating phenomena, as can be seen on the vectorscope.*

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3. The computer control of the system

The total phase measuring system is controlled by a PDP-11 computer. The CAMAC data-acquisition system is used as the interface:

1) A relay multicomplexer controls a 16 channel diode switched HF multiplexer by feeding a current of 20 mA to the proper diode.
2) Two DAC's feed compensation voltages to the LF low-pass filter to compensate for bias voltages due to disturbing signals.
3) A 12 bit ADC measures the DC signals (proportional to $A\cos\phi$ and $A\sin\phi$ from the LF low-pass filter.
4) Push buttons are used to control the computer programs.

The following function can be executed via the push buttons:

1) Measure and store the initial bias voltages for each channel. These voltages are fed to the LF filter for bias voltage compensation.
2) Switch manually to a certain channel for visual inspection on the vector display.
3) Perform a measurement of all channels and display the measured phases and amplitudes on a VDU.
4) Start a single control action to control the radial phase behaviour to predetermined values. At EUT the power supplies of the concentric correction coils are controlled by the computer via stepper motors and a stepper motor control unit in CAMAC;
5) Start an automatic control loop to keep the radial phase behaviour at predetermined values.
6) Perform a measurement of the energy of the particles of the external cyclotron beam.

4. Performance

1) Depending on the turn separation, pick-up signals of 300 - 1000 uV/uA beam current are measured.
2) Under worst case conditions an instability of about 1 nA is observed.
3) With beam currents larger than 50 - 100 nA the HF-phase of the particles can be measured with an accuracy of less than 0.5^{o}.
4) With well defined external beams of 100 nA and a phase width of about 6^{o} a relative accuracy of 5.10^{-4} in the energy of the particles in the external beam guiding system could be obtained at EUT.

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