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SINGLE BEAM INSTABILITIES IN DORIS

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Summary

In the electron- and positron rings of DORIS strong transverse and longitudinal single beam instabilities were observed, which caused current limitations. The severest transverse and longitudinal instabilities were induced by excitation of higher modes in the rf-cavities. When these instabilities were cured by damping the higher cavity modes, the thresholds for this type of instabilities were greatly increased. The origin of the remaining transverse and longitudinal instabilities is not yet understood. The thresholds of these instabilities were increased by Landau-damping and changing the betatron- and synchrotron frequencies from bunch to bunch. The head-tail effect was observed at high peak currents and was cured by compensating the chromaticity.

In the electron ring a transverse instability is present which is induced by the ions. Ion clearing in combination with some vacuum improvements is sufficient to avoid this instability.

1. Cavity induced instabilities

The severest single beam instabilities observed in DORIS were induced by the excitation of higher parasitic modes in the rf-cavities. Except for a very short filling of the ring (10 to 20 bunches) the current limitation was nearly independent of the circumferential distribution of the bunches, so that mainly the mean currents were limited. The thresholds for the transverse and longitudinal instabilities appeared in the range of 1 to 5 mA. However, the thresholds and the maximum currents, that could be stored were strongly correlated to the tune of the 8 cavities in each ring, so that by varying the tune of the cavities at random 200 mA could be stored or even more.

It turned out, that the transverse instabilities were induced by higher deflecting modes of the rf-cavities, while the longitudinal instabilities were induced by higher accelerating modes.

After improvement of the detecting equipment rf-signals from the beam picked up from wide-band electrodes in the rings and from loops in the cavities, were spectrum analysed.

In the beam and in the cavities we found higher-mode-frequency signals, coincident with the excitation of instabilities.

In order to identify the higher cavity modes causing the instabilities a special program of mode spectroscopy was started, based on the following properties of the beam:

the homogenously filled beam of 480 bunches can oscillate in 480 states (modes) m for each the transverse

$$m_\perp = 0, \ldots, 479$$

and the longitudinal case

$$m_\parallel = 0, \ldots, 479$$

For each mode $m_\perp$, $m_\parallel$ there appears a family of frequencies in the beam:

$$f^{\pm}_{\nu_\perp, m_\perp} = \left(\nu_\perp \cdot 480 \pm (m_\perp + \delta Q)\right) f_o, \quad \nu_\perp = 0,\ldots,\infty, m_\perp \text{ fixed} \tag{1}$$

$$f^{\pm}_{\nu_\parallel, m_\parallel} = \left(\nu_\parallel \cdot 480 \pm (m_\parallel + Q_s)\right) f_o, \quad \nu_\parallel = 0,\ldots,\infty, m_\parallel \text{ fixed}$$

($\nu_\perp, \nu_\perp$ run from zero to infinity according to the Fourier components of the beam, $f_o \triangleq$ revolution frequency.)

Thus the observable frequencies are multiples of the revolution frequency shifted by $\delta Q \cdot f_o$ ($\delta Q \triangleq$ fractional part of the Q-value) in the transverse case and by $Q_s \cdot f_o$ (synchrotron frequency) in the longitudinal case.

If a transverse instability is excited by a higher parasitic deflecting mode at the resonant frequency $f_{res\perp}$ we find from the theory [1] that this frequency must be of the form

$$f_{res\perp} = f^-_{\nu_\perp, m_\perp} = \left(\nu_\perp \cdot 480 - m_\perp - \delta Q\right) f_o \tag{2a}$$

If a longitudinal instability is excited by a parasitic accelerating mode at $f_{res\parallel}$, this frequency must be of the form

$$f_{res\parallel} = f^+_{\nu_\parallel, m_\parallel} = \left(\nu_\parallel \cdot 480 + m_\parallel + Q_s\right) f_o \tag{2b}$$

We found the cavity modes which caused the instabilities by arranging the frequencies observed from the electrodes and from the loops according to the families: within each family only members with a shift $-\delta Q \cdot f_o$ in the transverse case and with a shift $Q_s \cdot f_o$ in the longitudinal case are candidates for the resonant frequency. At the resonant frequency a large signal must also appear in the cavity loop. For mode identification we compared the observed candidates with the theoretically calculated higher mode frequencies for our cylindrical cavities. Also the theoretical coupling impedances for the transverse motion $Z_\perp$ and the longitudinal motion $Z_\parallel$ were calculated [1,2] (typical value: $Z_\perp \approx Z_\parallel \approx 1 M\Omega$) for the unique determination of the higher cavity modes.

From the analysis we obtained the following result: i) transverse instabilities were excited by the TM110-(780 MHz) and the TM111-(930 MHz) deflecting modes: the vertically (horizontally) displaced beam coupled to the vertically (horizontally) varying electric field excites the cavity and the horizontal (vertical) magnetic field deflects the beam vertically (horizontally).

The observed frequency family for the TM110-mode was found to be (depending on the cavity tune)

$$f_{res\perp} = f^-_{2,213} = 777.6045 \text{ MHz} - \delta Q \cdot f_o$$

$$f^+_{2,213} = 1221.0578 \text{MHz} + \delta Q \cdot f_o$$

$$f^{+}_{1,213} = 721.3922 \text{ MHz} + \delta Q \cdot f_o$$

$$f^{-}_{1,213} = 277.9389 \text{ MHz} - \delta Q \cdot f_o$$

ii) longitudinal instabilities were excited by higher accelerating modes: TM011 (740 MHz), TM022 (1200 MHz), TM022 (1585 MHz and modes above 1800 MHz.

Since it was not possible to operate the cavities in a reproducible way avoiding dangerous modes, there was need for damping the exciting cavity modes keeping the influence on the fundamental mode small. For this purpose special water-cooled radial antennae were developed which couple to the transverse electric field of the modes. The energy is transferred to a coaxial system where it is absorbed by iron material with a high permeability. Two absorbing systems work for each cavity and modes with transverse electric fields can be damped down by a factor 2000. The TM110-mode (no transverse electric field) is still present, however, we avoid crossing this mode by a proper cavity tuning during control. Above 1200 MHz the modes begin to propagate in our chamber. We put ferrite material in the chamber between the cavities for an over all damping of all these modes.

2. Transverse "multi-modes"

When it was possible to accumulate higher currents - after the cavity modes had been damped - transverse instabilities appeared again and limited the currents. These instabilities increased the horizontal and vertical beam size and - depending on the optics - limited durrents to values between 150 and 300 mA. The instabilities appeared in coincidence with about 15 betatron oscillation lines density spaced around the multiples of the radio frequency ($480 \cdot f_o = 499.666$ MHz). These instabilities caused a mean current limitation. Using octupol magnets we can increase the "multi-mode" threshold from 20 to 70 mA. An rf-quadrupole which works on the 15th harmonic of the revolution frequency and provides a maximum Q-split of 0.03 can increase the threshold by a factor 6, so that we can reach about 450 mA without an increase of the beam size due to the "multi-mode" instability. The interaction mechanism of this instability is not yet understood.

3. Head-tail effect

Head tail instabilities limited the average current to 0.25 mA/bunch. After over-compensating the negative chromaticity with sextupole magnets to small positive values we reached 15 mA/bunch at 2 GeV.

4. Longitudinal instabilities

At higher currents (> 200 mA) longitudinal instabilities appear which at present seem to limit the luminosity due coherent and incoherent bunch lengthening. At the moment we do not know, whether these instabilities are connected with higher cavity modes which are not sufficiently damped.

We can reduce the influence of these instabilities on the luminosity by splitting the synchrotron frequencies from bunch to bunch operating one of our two transmitters in each ring on the 481st harmonic of the revolution frequency.

5. Ion instabilities

In the electron ring we observed a transverse (mainly vertical) instability which disappeared when the electrodes for ion clearing were put to 10 KV and a gap (10 %) in the circumferential ring filling was present. As the vacuum improves this instability is not important.

References

1. R.D.Kohaupt,"Excitation of a Transverse Instability by Parasitic Cavity Modes", Internal Report DESY H1-74/2 (May 1974)

2. J. Gareyte, R.D. Kohaupt, A. Piwinski,"Instabilities of the Coherent Longitudinal Oscillation of the Bunch-System", Spring study on accelerator theory, CERN (1972).