MASTER

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SUMMARY OF LONGITUDINAL INSTABILITIES WORKSHOP*

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A five-day ISABELLE workshop on longitudinal instabilities was held at Brookhaven August 9 - 13, 1976. About a dozen outside accelerator experts, both from Europe and the USA, joined the local staff for discussions of longitudinal instabilities in ISABELLE. An agenda of talks was scheduled for the first day of the workshop (Appendix I). Later during the week, P. Channel gave a presentation on the subject "A more rigorous treatment of Landau damping in longitudinal beam instabilities".

Because the number of participants was not unduly large, it was possible to proceed with the preparation of reports and very informal discussions among small groups of individuals. A few progress meetings were held in which disagreements regarding calculations of coupling impedances were clarified. A summary session was held on the last day.

Heavy emphasis was put on single bunched beam instabilities in the microwave region extending above the cut-off frequency of the ISABELLE vacuum chamber. During the 1975 Summer Study¹ it became clear that the prevention of longitudinal microwave instabilities might indeed be one of the most difficult design problems in ISABELLE. This conclusion was based on recent observations of such instabilities at both the ISR and the PS (CERN) and, further, on theoretical work explaining their behavior quantitatively. The effect seemed most hazardous for the AGS bunches during their acceleration from the injection orbit to the stack. It could cause a blow up of the longitudinal phase-space area of the bunches thus limiting the total current in ISABELLE

*P.J. Channel, A.W. Chao, E.D. Courant, A. Garren, R.L. Gluckstern, S. Giordano, H. Hahn, H. Hereward, J.C. Herrera, D. Johnson, L.J. Laslett, E. Messerschmid, D. Möhl, M. Month, G. Parzen, R.F. Peierls, E.C. Raka, F.J. Sacherer, P. Wilson, B. Zotter.

1. W. Schnell, Proc. 1975 ISABELLE Summer Study, Brookhaven, BNL 20550, p. 126.

to a value below the design intensity of 10 A. To avoid these instabilities the longitudinal coupling impedance (Z/n) of each ring will have to be of the order of a few ohms.

The workshop was asked to address itself to three major aspects of the above problem: Further understanding of the mechanism governing the instability and calculations as well as measurements of the longitudinal coupling impedances in the ISABELLE rings.

Regarding the mechanism of the instability, theory was further extended at the workshop to include the dependence of the threshold current on not only the coupling impedance but also on the quality factor (Q) of the parasitic resonator whose induced voltage is the cause of the instability. Two main contributions to this subject were made.

Numerical calculations performed earlier by Messerschmid and Month² had indicated that the single bunch microwave instability was determined by the local Keil-Schnell criterion for resonator bandwidths of the order of the bunch width but that higher threshold currents were obtained for increasing Q -values. Messerschmid and Month³ carried out further computations during the workshop and also formalized a theory trying to explain the observed results in a quantitative way. Their continued computer simulation showed that for sufficiently high Q values, corresponding to a bandwidth equal to the spacing of individual normal ring modes, the single bunch instability was determined by the ordinary coasting beam threshold criterion. Moreover, it was found that there was a transition region for intermediate values of Q where threshold currents lie between those predicted by the two criteria.

The theory put forward in connection with these results assumes that the instability takes place on a much faster time scale than the

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2. E. Messerschmid and M. Month, Nucl. Instrum. Methods 136, 1 (1976).
  3. E. Messerschmid and M. Month, these Proc.

synchrotron motion. On this basis the latter is ignored and the ordinary coasting beam theory is applied. An effective impedance, Z_{eff} , is introduced describing the response of a resonator with impedance Z to a normal mode perturbation superimposed on the unperturbed charge distribution of the bunch. It is shown that this combination, for low Q values, excites a series of modes, equal to $1/B$ in number, where B is the bunching factor. The effective impedance is equal to the sum of the impedances of these modes which equals to Z/B . In this way the local Keil-Schnell criterion is obtained. As Q increases the number of excited modes decreases, and when a single mode remains, the ordinary coasting beam criterion applies.

Sacherer⁴ also treats the single bunch microwave instability theoretically. According to his earlier theory on longitudinal bunched beam instability, the single bunch mode is stable to first approximation. However, he concluded during the workshop that instability can occur due to coupling of adjacent multipole modes when the beam induced voltage becomes comparable to the applied rf voltage. If the bandwidth of the resonator is smaller than the spacing between the normal ring modes only one spectrum line at most contributes to the instability. For growing bandwidth the resonator will cover more and more lines until it reaches a value of $1/\tau$. Here τ is the bunch width and also the width of the overlap of two adjacent multipole charge distributions. This leads to the same dependence of threshold current on the Q of the resonator as was found both on a simulated computation and theoretically by Messerschmid and Month.³ Work is in progress to determine the exact threshold duration.

Theoretical estimates of actual impedances seen by the beam got a great deal of attention. A more detailed summary of this subject was prepared by Zotter⁵ during the workshop.

Relative contributions from cavities in the form of vacuum ports, etc. and from the connecting vacuum tube sections at frequencies where

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4. F.J. Sacherer, these Proc., p.

5. B. Zotter, these Proc., p.

the pipe can support propagating modes were discussed. Cavity contributions (resonance impedances) have been calculated in the past and are known to yield rather high values. (A procedure similar to that used at the ISR will have to be used in order to de-Q these cavities and to lower their coupling impedances by several orders of magnitude.)

The vacuum chamber contributions were evaluated in several ways. Impedance calculations based on field matching, put forth by Month and Peierls⁶ prior to the workshop, indicated extremely sharp resonances and high values for Z/n . During the workshop it was concluded that these findings were a result of neglecting the wall resistivity of the pipe sections. Gluckstern⁷ developed a different approach in which the periodic cavities were viewed only as means of bringing the phase velocity of propagating mode close to the beam velocity. The effect of the discontinuity region is characterized by two parameters related to the reflection and transmission coefficients of the discontinuity alone. Revised results from the field matching calculations⁸ and those obtained by Gluckstern now yield a comparable value of several ohms for Z/n of the pipe sections in ISABELLE. (This also agrees with earlier estimates by Faltens and Laslett,⁹ viewing the pipe section themselves as resonance cavities.)

In view of this, the ISABELLE vacuum chamber material is now being reconsidered. Changing from aluminum to stainless steel would reduce Z/n of the rings by a factor of seven, bringing the contributions of the tube sections down to the order of one ohm.

The subject of different techniques of impedance measurements was only briefly dealt with. In addition to the measurements of the dis-

continuities mentioned in the previous paragraph, the pros and cons of more conventional methods of determining resonant impedances of parasitic cavities were discussed.

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6. M. Month and R. Peierls, "Coupling Impedance Structure above the Tube Cutoff Frequency" to be published.
  7. R.L. Gluckstern, these Proc.
  8. M. Month, private communication.
  9. A. Faltens and L. J. Laslett, Proc. 1975 ISABELLE Summer Study, Brookhaven, BNL 20550, p. 486.

APPENDIX I

Workshop on Longitudinal Instabilities

August 9 - 13, 1976

Agenda

The Workshop will begin at 9:30 in Bldg. 923.

Opening Remarks	J. Sanford	9:30
Introduction	R. Chasman	
General Comments on Microwave Instabilities	M. Month	
Longitudinal UHF Instability in a Bunch	H. Hereward	
Bunched Beam Longitudinal Instabilities and their Extension to High Frequencies	F. Sacherer	
Numerical Simulation of the High Frequency Longitudinal Instability of Bunched Beams	E. Messerschmid	
Lunch		1:30
Calculation of Longitudinal Coupling Impedance of Rings of Arbitrary Shape	R. Peierls	
Longitudinal Coupling Impedances in a Periodically Loaded Guide above Cutoff	R.L. Gluckstern	
Comparison between Calculations and Measurements of Longitudinal Coupling Impedances (Experience from the PEP Design with very Short Bunches)	P. Wilson	
General Discussion		
Coffee		3:30
Organization of Working Groups		