INDUCTION ACCELERATING CAVITY FOR A CIRCULAR RING ACCELERATOR*

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Abstract

This paper reports details of an induction-accelerating cavity employed in a circular ring. An outline of cavity design focusing on electrical and mechanical characteristics is given. Crucial properties of the induction cavity such as inductance, stray capacitance, and resistance representing eddy current loss and core excitation loss are discussed with measuring results. An operational scenario of the induction cavity in a hybrid scheme, where a single bunch trapped in the RF bucket is accelerated with the induction cavity, is explained.

INTRODUCTION

An induction cavity employed for the POP experiment [1] to verify the induction synchrotron concept [2] has been developed. It is expected to be capable of generating an accelerating voltage of 2.5kV with a pulse width of 250nsec at a repetition rate in the range of near 1MHz. After careful designing and necessary R&D works, four cavities have been assembled at the KEK. After completing low power tests, three cavities have been installed in the KEK 12 GeV main ring as seen in Figure 1. The residual cavity is on CW high power test, connecting to the power modulator. The design procedure with respect to electric and mechanical parameters is briefly given. In order to know its actual circuit parameters, the cavity has been driven by a low power pulser through the transmission cable at the test bench.

Figure 1: A set of installed induction cavities in the KEK-PS

Meanwhile, the cavity has been driven by a single RF proton bunch through the entire acceleration cycle. Transient reaction of the cavity observed at the feeder edge provides useful information. Measuring results are presented and their analysis is discussed. At the first stage of the POP experiment, a single bunch captured in the RF bucket is going to be accelerated with these three induction cavities. This kind of hybrid acceleration requires our particular attention on the operational procedure.

DESIGN OF INDUCTION CAVITY

The design process of the induction cavity, which is driven by a rectangular-shape voltage-pulse, is notably different from conventional RF cavities or induction cavities for linear induction linacs. Its design process is shown in a flow chart as seen in Figure 2. First of all, a desired induced-voltage shape is determined from the acceleration requirement. To achieve a sufficient flat-top length in the induced voltage, the cavity must have large inductance. The droop, which is known to affect the beam stability of the super-bunch [3], has to be minimized as small as possible. To realize a fast rise-time, small capacitance is crucial. Coupling impedances are of concern as well as a conventional RF cavity. Its estimation based on the structure has been performed and the longitudinal and transverse impedances have been measured by using a Network analyzer. After confirming the performance at a full power operation, the cavity will be installed into the beam line.

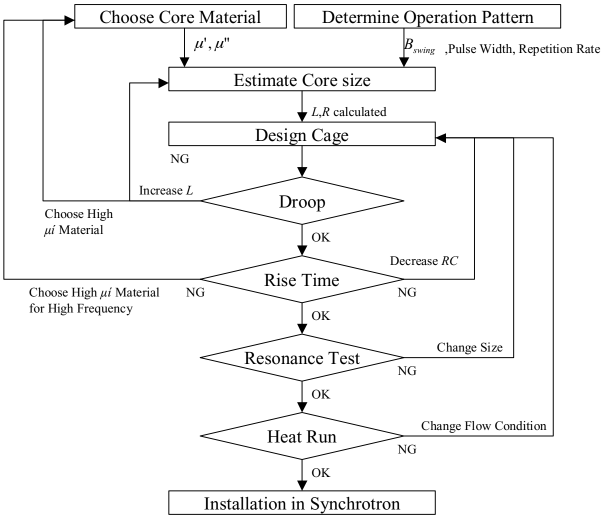

Figure 2: From design to installation

MEASUREMENTS OF CAVITY CHARACTERISTICS AND THEIR ANALYSIS

Drive by a RF Proton Bunch

A proton beam is an ideal driving source to confirm the cavity parameters, because a reaction to the beam is ignorable. An RF-bunch current $i_b(t)$ and voltage $V_M(t)$ induced between input and output in the power feeding line are measured through the entire acceleration cycle. A wide range of pulse shape is obtainable, because the bunch length drastically change with acceleration, that is, 90 nsec at injection, 15 nsec at transition crossing, and 400 nsec after start of debunching, In the measurement, several extreme attenuation resistances or capacitance are connected in parallel to the main circuit in order to manifest the cavity parameters.

Here a LCR parallel circuit is assumed as an equivalent circuit for the induction cavity as shown in Figure 3, and additional parameter to the cavity for the extreme case is shown in Table 1.

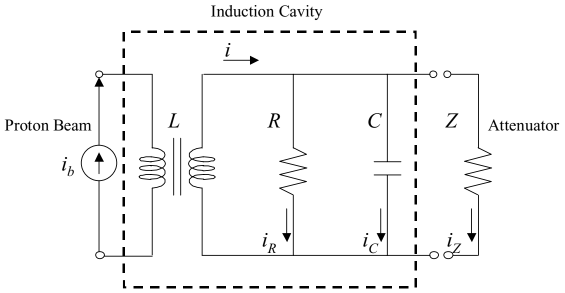

Figure 3: Equivalent circuit for the induction cavity

Table 1: External parameters for the extreme cases

case	$Z[\Omega]$	Additional CapacitanceC^*[pF]	Pulse width[ns]
A	60	0	15
B	60	0	80
C	60	0	400
D	60	1000	15
E	1000	0	15

The induced voltage by a Gaussian-shaped beam pulse is given in the following analytic formula,

$$i_z(t) \equiv \frac{V_M}{Z} = \left(-\frac{1}{\beta CZ}\right)\int_0^t e^{-\alpha(t-t')}\sinh\beta(t-t')\,\dot{i}_b(t')dt',$$

where

$$2\cdot\alpha = \frac{1}{C}\left(\frac{1}{Z}+\frac{1}{R}\right)$$

$$\alpha^2+\beta^2 = \frac{1}{LC}$$

Now let assume L is a design value, that is, 110μH, C_0 and R are unknown. Then, C_0 (=C-C*) and R are determined so that the analytic solution best fits with measuring results for 5 extreme cases with respect to a peak, position in time giving the peak, and tail-shape. Eventually the parameter C_0 = 260pF and R = 330 Ωis obtained. It is confirmed that obtained parameters are consistent to the design values. The comparison of measurements and analysis is shown in Figure 4 A - E. The result supports that the equivalent circuit model is appropriate to express the induction cavity.

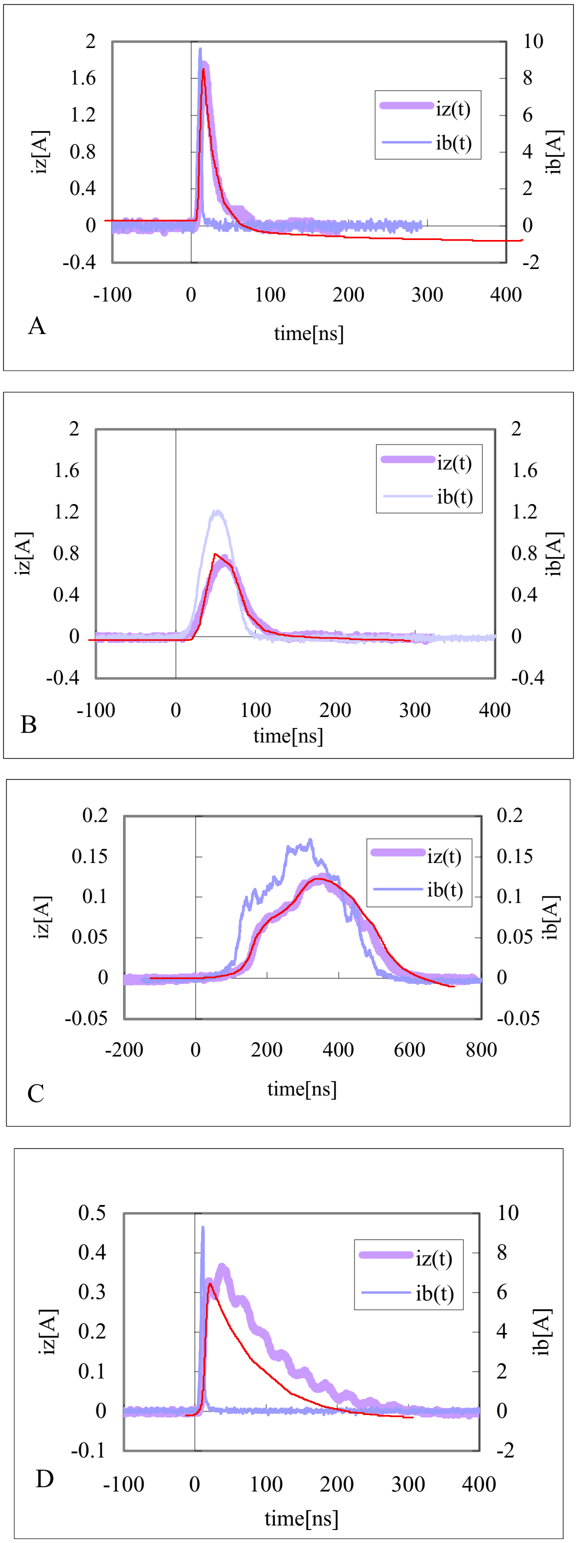

Figure 4: Measuring results and analytic solutions

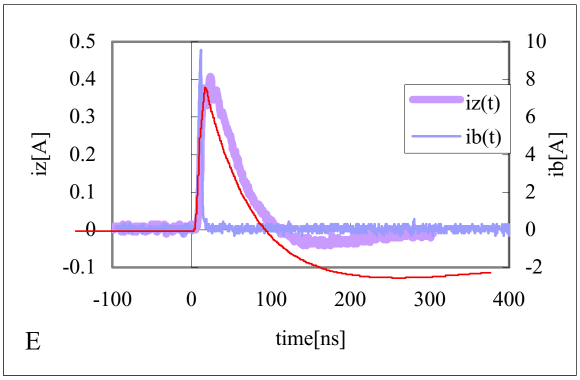

Figure 4: Measuring results and analytic solutions (continued)

1ST STAGE OF POP EXPERIMENT

The main components employed for the POP experiment are shown in Figure 5. First of all the required 2.5kV voltage-pulse is generated in the modulator connected the DC power supply. The voltage pulse propagates through the transmission cable of 40m in length and 125Ω to excite the induction cavity, which is attached in parallel to the resistance of 210Ω for matching. The existing RF cavity is used for longitudinal confinement. Here the induction cavity is employed just for acceleration.

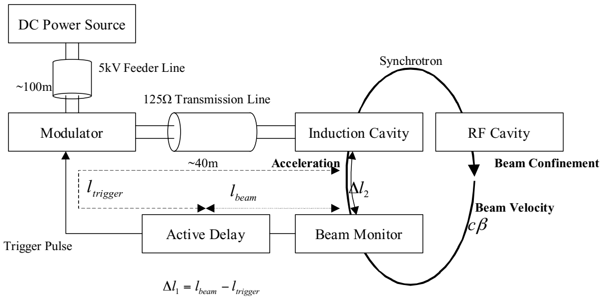

Figure 5: POP Experiment (1^{st} stage)

CONTROL SCENARIO FOR INDUCTION ACCELERATION OF THE RF BUNCH

In the POP experiment, a master trigger of the modulator takes an important role. The induction cavity must be fired when the RF bunch passes through the cavity. Namely the master trigger signal has to be always synchronized with beam revolution. Now the synchronization condition is written in the following relation,

$$\left(\frac{\ell_{beam}}{v_{electric}}\right) + \tau_{delay} + \left(\frac{\ell_{trigger}}{v_{electric}}\right) = \left(\frac{\Delta\ell_2}{c\beta}\right) + n\cdot\frac{C_0}{c\beta}$$

where

$v_{electric}$: the velocity of signal through coaxial cables
$c\beta$: the revolution velocity of beam
C_0 : the ring circumference
ℓ_{beam} : the length of the signal cable from the beam monitor to the active delay
$\ell_{trigger}$: the total length of the signal and driving pulse cables from the active delay to the induction cavity
$\Delta\ell_2$: the physical distance from the beam monitor to the induction cavity
n : allowed revolution delay (integer)

All parameters except for β are constant in time, as seen in Figure 5. If we choose RF clock as a master clock in this trigger system, a change of τ_{delay} in time may be shown in Figure 6, where a solid yellow line stands for a desired delay expected from the RF clock associated with acceleration. This delay is generated by a DSP with GHz clock frequency.

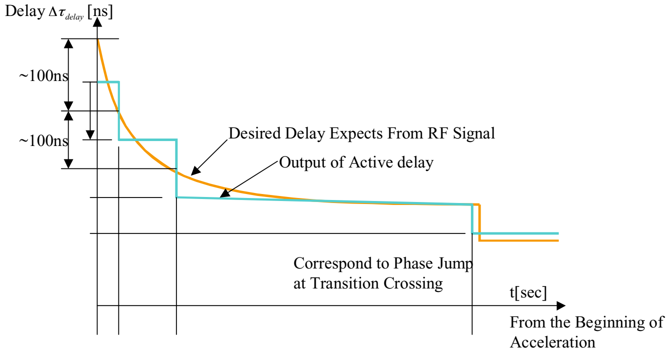

Figure 6: A schematic example of the discrete active delay

SUMMARY

A story of induction cavity development for the induction synchrotron has been presented, focusing on the design procedure and measurements of its characteristics using a proton beam of the KEK 12GeV PS. This work is supported by Grant-In-Aid for Creative Scientific Research (KAKENHI 15GS0217)

REFERENCES

[1] Ken Takayama and J.Kishiro, Nucl. Inst. Meth. A 451, p304 (2000).
[2] Yoshito Shimosaki, in this proceedings.
[3] Kota Torikai et al., ìDesign Study of 1 MHz Induction Cavity for Induction Synchrotronî, PAC03, May 2003, p1784.
[4] Kunio Koseki et al, ìR&D Works on 1MHz Power Modulator for Induction Synchrotronî, PAC03, May 2003, p568.