# FAST BEAM CHOPPER WITH MA CORES

Y. Mori, M. Muto, C. Ohmori, Y. Shirakabe[1], A. Takagi, KEK, Tsukuba, Japan
W. Chou, FNAL, Batavia, IL60510, USA

*Abstract*

A new type of fast beam chopper is developed and tested. The chopper is basically a periodic beam energy transformer which performs 10% modulation of beam's kinetic energy. The modulated fraction of the beam is chopped off by a downstream RFQ due to the relatively narrow injection energy window of the RFQ.

The chopper uses magnetic-alloy cores and a fast high-voltage transistor switch in order to produce output voltage pulses with short rise- and fall-time and a good flat-top. The chopper system, that includes a chopper cavity and a pulsed power supply, is installed at the HIMAC facility. Test operations so far demonstrate that an efficient chopping can be obtained with this type of chopper. Capture experiments of the chopped beam at the HIMAC main-ring, as well as improvements of the chopper power supply, are on the way.

## 1 INTRODUCTION

Development of an efficient beam chopper is one of the key issues in realizing high intensity accelerators. If a continuous beam from an ion source is directly injected into linacs, the output beam from the linacs will contain a certain periodic fraction which can not be captured by succeeding circular accelerators. The beam loss caused by this mismatching of the time-structures results in serious radiation problems at the rings. Chopping-off of the unnecessary fraction of the beam will solve this situation.

Another important issue for the chopper is a limited space allocable to it. In order to inject the possible maximum intensity of an ion source beam into a linac, the low-energy beam transport line should be as short as possible. It is therefore impossible to allow the chopper to occupy a certain length, for example 1m, as is the case in a conventional transverse-kicking chopper.

Consequently, our R & D goal for the chopper can be settled as following: to realize an efficient chopper within a minimal mechanical length in a beam direction.

The new type of chopper we present here is basically a beam-energy modulator which utilizes a relatively narrow injection-energy window of an RFQ linac.

## 2 PRINCIPLE OF CHOPPING

An RFQ linac can accelerate a beam with a specific injection energy. For example, in the case of HIMAC, the heavy ion medical accelerator for cancer therapy in Chiba, Japan, the injection energy of the RFQ is 8 keV/nucleon. It has been known, by numerical simulation[1], that when the injection energy is modulated for 10%, no matter if it is in the higher side or in the lower side, the beam transmission through the RFQ goes down to zero, as is shown in Figure 1. The figure also shows our recent transmission measurement on HIMAC-RFQ, using a $He^{2+}$ beam from an 18 GHz ECRIS. After normalizing the measured values to the simulation at 0% modulation, it is seen that both curves show the similar inclination.

From these facts, it is clear that 10% modulation of the injection beam energy will achieve the chopping-off of the beam. Since the injection energy is 8 keV/u, the ion source voltage should be, for example, 16 kV for $He^{2+}$ and 32 kV for $He^{+}$. 1.6 kV and 3.2 kV, respectively, are sufficient values to achieve 10% of modulation. If an inductive voltage generator can provide this range of voltage along the beam axis, it can work as an effective beam chopper.

## 3 HARDWARE

The chopper system is composed of two main parts; a chopper cavity and a pulsed power supply. They are designed to deliver an alternating voltage output with an amplitude of ±5% of injection beam energy. When the

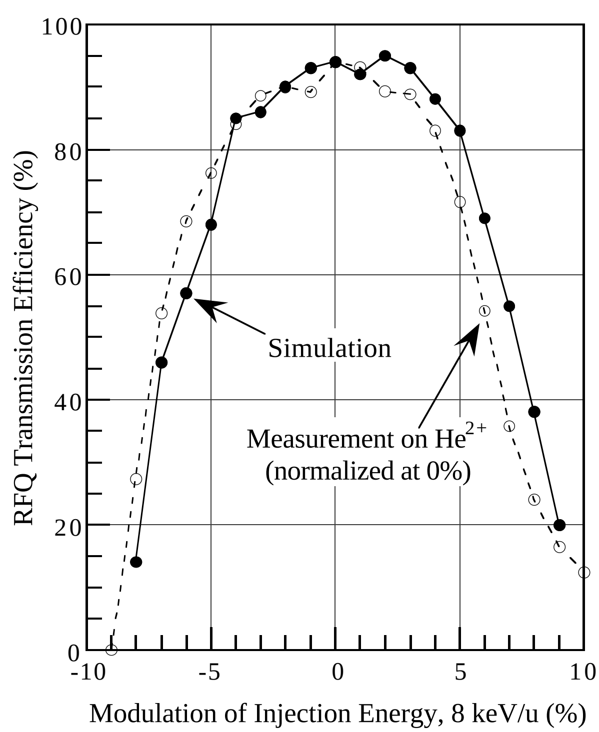


Figure 1: Simulated and measured RFQ transmission efficiency as a function of the injection energy modulation. Since the measured values contain a certain transport loss, they are normalized so that the measurement agrees with the simulation at the 0% modulation.

[1] yoshihisa.shirakabe@kek.jp

beam is to be chopped, the ion source voltage is first shifted for either +5% or -5% of the normal value. If the shift is +5%, the beam is chopped off when the chopper voltage is +5%, and the beam can transmit the RFQ when the chopper voltage is -5%. If the shift is -5%, the beam is equally chopped off with an inverse phase. In both cases, it is important to obtain voltage waveforms with short rise- and fall-time and good flat tops.

## *3.1 Chopper Cavity*

The chopper cavity is composed of three magnetic-alloy cores, a ceramic gap, and a copper shield, as is shown in Figure 2. In our preparatory study[2] on the choice of magnetic core materials, it was demonstrated that the magnetic-alloy (finemet) is better suited for the chopper core compared to ferrite materials.

The mechanical length of the cavity in the beam direction is 11.6cm, including three MA-cores and the copper shield. This is short enough to be installed in a limited distance of a low-energy transport line.

Each core has 504mm outer-diameter, 158mm inner-diameter, and 25mm thickness. One core weighs about 30 kg. The chopper cavity has ~120kg in total weight.

The primary voltage is supplied on the chopper through an one-turn coil. The upper-half of the copper shield is made as a detachable unit so that the coil can be easily exchanged.

## *3.2 Pulsed Power Supply*

The pulsed power supply is designed to deliver output voltage pulses of up to 2 MHz. The possible maximum high voltage is designed to be 8 kV, which means bipolar pulses of up to ±4 kV can be generated. Stable operations of up to 5 kV (±2.5 kV bipolar) are so far tested. In our current experiment site, HIMAC, the maximum required voltage is 3.2 kV (±1.6 kV bipolar).

In order to obtain fast switching, a high-voltage bipolar transistor switch HTS 81-06-GSM made by BEHLKE, Germany, is used. The typical duration of rise and fall of this switch is about 10 nsec. In our actual

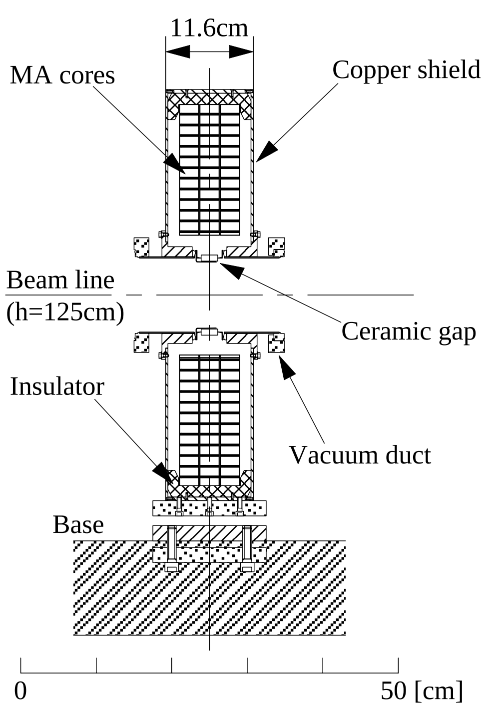


Figure 2: Side view of the chopper. Three magnetic-alloy cores with 504mm ø$_{out}$ x 158mm ø$_{in}$ x 25mm thickness are used. An one-turn coil is wound around the cores.

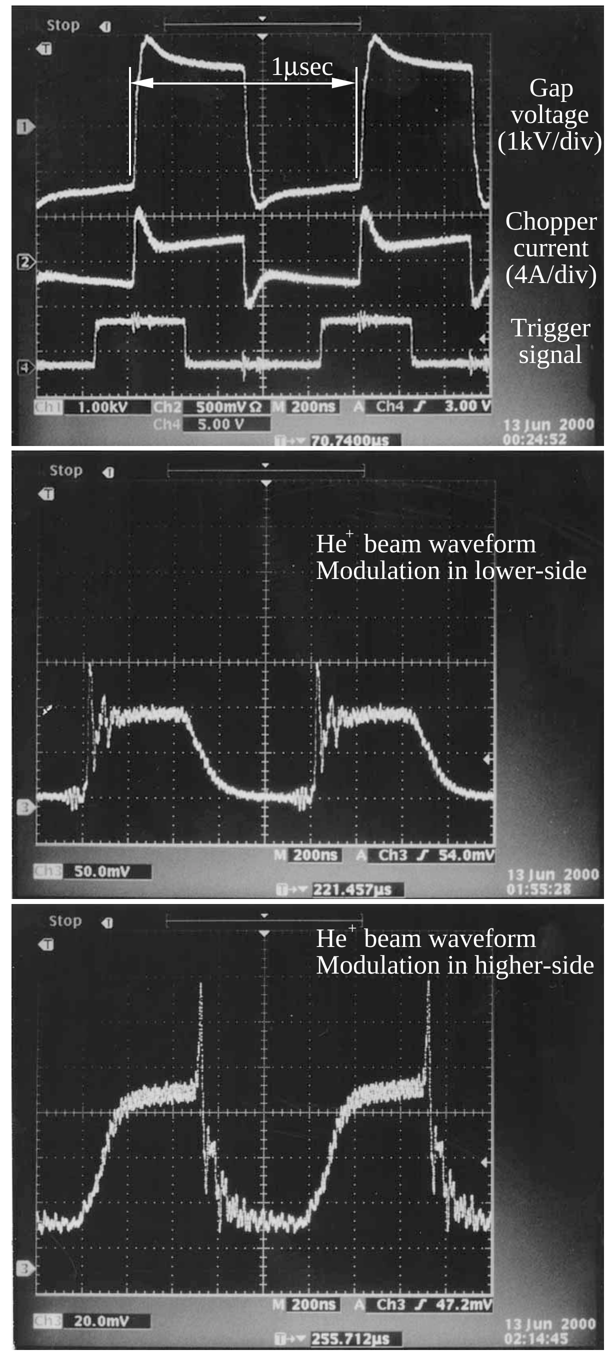


Figure 3: Observed results of chopping. The gap voltage rises and falls in ~50 nsec (top). The chopping is effectively achieved both in lower-side and in higher-side modulation (middle and bottom). A difference between them is a sharp peak position that appears at the edge of each pulse.

power supply system, it is found to be around 50 nsec.

## 4 EXPERIMENTS

### 4.1 Chopping with He Beam

The chopping of the beam is effectively demonstrated, as is shown in Figure 3, using a $He^+$ beam from the 18 GHz ECRIS of HIMAC. Although the gap voltage shows a certain droop, it does not seem to seriously affect the chopping effect, probably thanks to the flatness of the transmission curve around 0% modulation.

Both the lower-side modulation and the higher-side modulation show the equally effective chopping (Figure 3, middle and bottom). The difference between them is the position of the sharp peak, which is at the front-edge of each beam pulse in the lower-side modulation, and at the rear-edge in the higher-side modulation. This can be explained as a 'slope-effect' of the gap voltage. In the lower-side modulation, for example, the beam pulse starts at the rising edge of the gap voltage. Since its rise is not ideal but follows a certain slope (Figure 3, top), the fraction of the beam that crosses the chopper at the slope gains less kinetic energy, therefore becomes slower, compared to the following fraction that comes at the flat top. Thus the difference of velocity of each fraction results in the effective concentration of the beam intensity. This is effectively a beam bunching, which may become, with a proper adjustment of the voltage pulse shape, another use of this type of chopper.

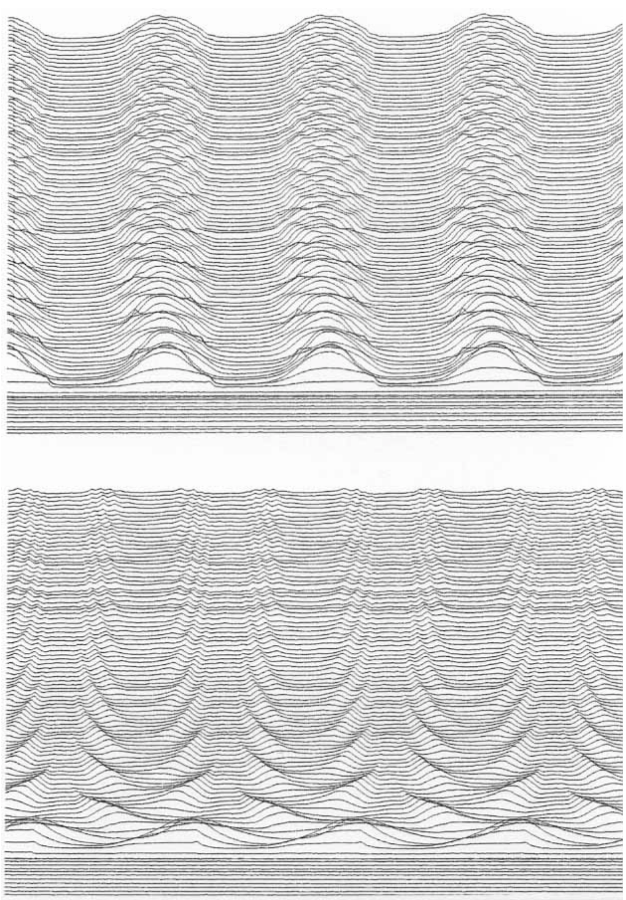

Figure 4: Captured beam profiles observed at the HIMAC main-ring. The horizontal span corresponds to ~4 μsec. Each line is plotted with an 100 μsec time interval. The top figure is the case of the injection onto the stationary RF buckets. The bottom is the contrary case.

### 4.2 Capture at the Main-ring

The beam chopping introduces a time-structure onto the injection beam of the main-ring. Thus the chopping gives a new means of beam diagnosis at the main-ring, as well as the reduction of the beam loss at the capture process. After the intended chopping is obtained, the main-ring capture study using the chopped beam is started. Figure 4 shows an example of preliminary results.

Both the top and bottom figures of Fig. 4 show the mountain range plot of the main-ring beam signal. Each single line denotes ~4 observed chopped beam pulses, meaning that the horizontal span corresponds to ~4 μsec. Every two lines have a time interval of 100 μsec. Each line shows the variation in the phase space of the beam bunches captured in the main-ring

With the chopping of a 50% duty-factor, it becomes easier to observe the bunches to be injected and captured by the RF buckets. The top figure is the case when the beam bunches are injected onto the stationary region of the RF buckets with the well-tuned injection timing. The stable periodic appearance of the bunches in all the lines demonstrates the adequate capture onto the RF buckets. The change of the bunch shapes from one line to another displays the quadrupole oscillation. The bottom figure, contrary to the top, is the case when the bunches are injected onto the RF phase half a period away from the stationary region. It is seen that no stable capture of the bunches is achieved, as a natural sequence of the injection onto the unstable RF region.

## 5 SUMMARY

The new type of chopper is developed and the intended chopping effect is successfully achieved. The chopper is in principle a beam energy modulator which utilizes the narrow injection energy window of the downstream RFQ.

The efficient chopping results are obtained both in the lower-side and in the higher-side modulation. The beam capture experiment at the main-ring has started in order to demonstrate that an effective reduction of the beam loss at the capture process can be achieved with this new beam chopping. The preliminary results are shown, and more detailed study will be reported in due time.

## ACKNOWLEDGMENTS

The authors are deeply thankful to Dr. K. Noda, Dr. M. Kanazawa, and other HIMAC staffs for their thorough assistance in the installation of the chopper system and in the following chopper experiments.

## REFERENCES

[1] N. Toduda *et al*, Proc. 1992 Euro. Part. Accel. Conf., 548(1992).

[2] W. Chou *et al*, Proc. 1999 Part. Accel. Conf., 565(1999).