# POSSIBILITY ION ACCELERATION ON HIGHER MODES AT THE LINEAR ACCELERATOR WITH INTERDIGITAL-H ACCELERATING STRUCTURE

V.A.Bomko, M.I.Ayzatsky, B.V.Zajtsev, A.F.Kobets, B.I.Rudjak
NSC Kharkov Physical and Technical Institute, Ukraine

*Abstract*

Heavy ion linear accelerators based on interdigital-H accelerating structure has latent resources of particle acceleration at non-conventional modes of excitation of HF power. The results of investigations demonstrate that in the structures of prestripping (PS) and main section (MS) on the Kharkov heavy ion linear accelerator (MILAC) there is a real possibility to accelerate ions on the higher modes of H-type. The investigations were carried out on the models of accelerating structures PS and MS built in the scale 1:3. In the MS cavity the wave $H_{120}$ was excited that corresponds to $H_{121}$ for unloaded cavity. In the PS cavity having a rectangular shape, $H_{300}$ is an analogue of this wave (that corresponds to $H_{301}$ for unloaded cavity). In each of the given cases we managed to obtain the required distribution of the accelerating field using local and end resonant adjusting elements. With that there was essential difference in frequencies of excited waves. In the PS cavity the frequency increased by a factor of 1.6, while in the MS cavity the frequency only increased by a factor of 1.08. The frequency changes obtained allow to enhance accelerated particles energy in PS and MS without essential changes of the accelerating structure by a factor of 2.56 and 1.16, respectively.

## 1 INTRODUCTION

The interdigital accelerating structure (IDAS) developed in NSC KIPT for heavy ion acceleration [1] is used as the basis for newly designed multicharged heavy ion accelerator (MILAC). It was shown that this structure is highly efficient [2-4]. This accelerating structure offers advantages over the Alvaretz structure, among which the most important advantages are its compactness (it is possible to increase the operating wavelength (3-4 times), high shunt impedance (2-4 times), higher acceleration rate (2 times).

The interdigital structure inserted into cylindrical cavity radically transforms electric and magnetic field distribution of the initial $H_{111}$ wave creating a longitudinal component of electric field in the gaps between drift tubes. Earlier we designed special adjusting devices of resonance and non-resonance types. They allow to achieve uniform distribution accelerating field along the length of the cavity with transformation of $H_{111}$ mode into $H_{110}$ mode. The new procedure of transformation of sinusoidal electric field distribution along the gaps between drift tubes of increasing lengths showed high efficiency in new MILAC [2-5].

Together with $H_{111}$ wave in unloaded cavity there exist the multitude of modes of $H_{mnp}$ type, where indexes defines the number of field variations in azimuth, radius and cavity length, respectively. Several modes of both types were used in accelerating equipment. On their basis acute problems in physics of accelerators were solved. Besides the $E_{010}$ and $H_{111}$ wave, on which accelerating structures of Alvaretz and IDAS types were developed, $H_{011}$ and $H_{211}$ waves form the basis for structures with RFQ [6,7], $E_{020}$ wave - for structure with disks and washers [8]. Transformation of $E_{011}$ wave into $E_{010}$ allowed to solve the problem of smooth energy adjusting of accelerated ions in the Alvaretz structure[9]. The results of our investigations showed that in the IDAS structures excited on $H_{110}$ wave smooth energy variation of accelerated ion in (0.3-1) $W_o$ [10].

In the present report we discuss a new method of energy enhancement of accelerated ions in respect to the nominal energy.

## 2 CONCEPTS OF THE METHOD

In the cylindrical cavity among $H_{mnp}$ waves the lowest frequency corresponds to $H_{111}$ mode. Other modes with higher indexes differ significantly in frequency. For example, $H_{121}$ mode corresponds to resonance frequency 2.89 times higher than $H_{111}$ resonance frequency.

We concentrated our attention on this mode because distribution of its electric field in the region adjacent to the axis there is analogy with the field of $H_{111}$ wave. In the Fig.1 schematic field distribution of $H_{111}$ wave is presented and corresponding distribution for $H_{121}$ wave (Fig.2). With introduction of such high capacitive and inductive load, which the IDAS is, the situation can be radically changed and frequencies of these modes can approach each other dependently on the type of the load.

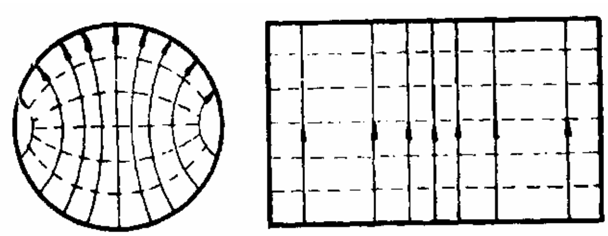

Fig.1 Schematic field distribution of $H_{111}$ wave

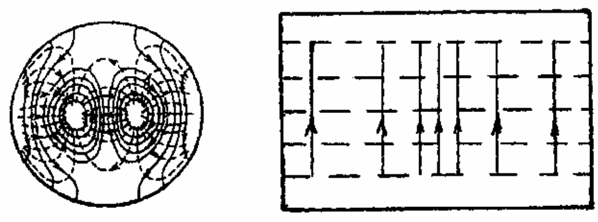

Fig.2 Field distribution for $H_{121}$ wave

The accelerating structure of the linear ion accelerator consists of a number of cells which lengths for $\pi$-wave are determined on the formula $L_n=\beta_n\lambda/2$, where $\beta_n$ is relative velocity of the synchronous particle; $\lambda$ - operating wavelength. Increase in a cell length per one HF-period is estimated approximately on the formula $\Delta L=qeE_nG_n\cos\varphi_s\lambda^2/(Amc^2)$, where $E_n$ is electric field averaged over a cell length, $G_n$ – transit time factor, $\varphi_s$ - synchronous phase; e, m - proton charge and mass; q and A - charge and mass number of the ion nucleus.

When the accelerating structure is excited on the frequency higher than the nominal one, to achieve the constant value of $L_n$ the particle velocity must be increased. That can be done with adequate selection of $E_n$ in tolerable limits or with decreasing q to A ratio. In this way it is possible to achieve certain gain in final energy of particles at the accelerator output compared with the nominal one.

## 3 EXPERIMENTAL RESULTS

We studied experimentally this problem on the basis of MILAC accelerator that was at our disposal. The main section represents a cavity 11.4 m in length and 1.5 m in diameter loaded with 40 drift tubes connected with the cavity on the interdigital principle.

The operating frequency is 47.2 MHz. The prestripping section has other geometrical parameters. A rectangular cavity 4m in length and transverse dimensions of 116 x 90 cm, is loaded 46 drift tube on the interdigital principle, too. There exist models of both sections constructed even before construction of the real structures. At them problems of accelerator design, methods of adjusting and forming of accelerating field distribution were solved and HF-characteristics were measured. This models are presented in Fig.3 and Fig.4.

The model of the main section is constructed in the scale 1:6 the frequency corresponding to operating $H_{110}$ mode was 282.3 MHz. this value is 2.46 times lower than the frequency in unloaded cavity. On this cavity we searched and identified higher modes. With that we determine clearly dispersion of $H_{11P}$ waves. Search of modes with the same field structure analogous to $H_{120}$ in rather far range gave no results. The discovery was unexpected: the frequency of this wave was only 310 MHz, that is, in differs from the frequency of the operating wave only 1.08 times. Field distribution along the axes of the structure excited on $H_{120}$ and $H_{110}$ is approximately the same.

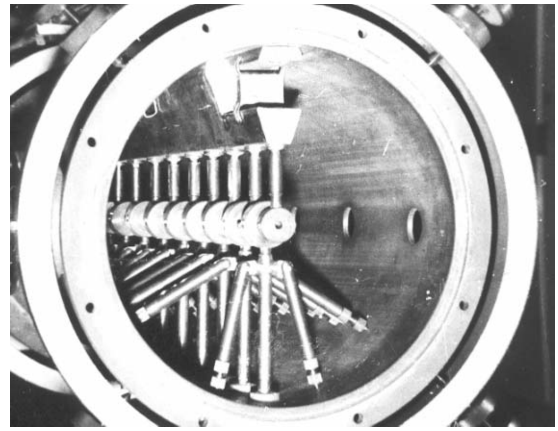

Fig.3. Model of the main section MILAC.

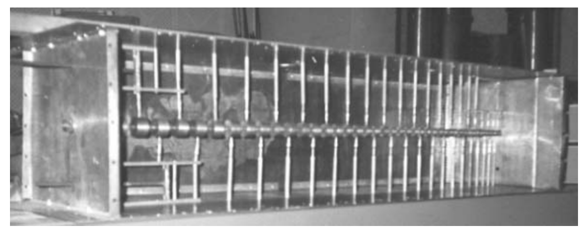

Fig.4. Model of the prestripper MILAC.

Such a small difference between $H_{120}$ and $H_{110}$ frequencies demonstrates that in a cavity loaded with IDAS structure for $H_{120}$ wave average variation of electric field distribution dominates (Fig.2), and side variations does not effect significantly HF-characteristics of the structure.

A somewhat different nature have waves of higher order in the structure of prestripping section. A rectangular cavity and a different construction of adjusting elements leads to other results. In the cavity of rectangular cross-section a unique procedure of wave numeration is used. A mode which is similar to operating mode is denoted with $H_{101}$ indeces , and a higher mode of interest is represented with a symbol $H_{301}$. Field distribution of $H_{301}$ mode is shown schematically in the Fig.5.

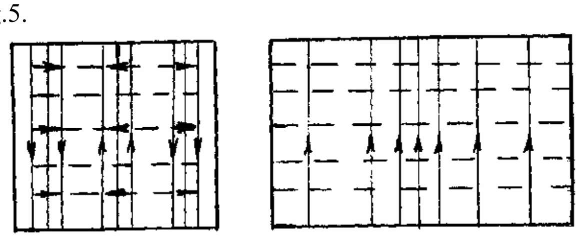

Fig.5. Field distribution of $H_{301}$ mode for rectangular cavity.

We carried out studies similar to those described above on the model of the prestripping section in the scale 1:3. The results showed that the frequency of required $H_{300}$ wave in the loaded cavity is 1.6 times higher than the frequency of operating $H_{100}$ wave; field distribution in gaps between drift tubes also is not uniform. Clearly, that has occurred due to the shift of resonance adjusting elements from the resonance. Finally, required uniform field distribution was formed with adjustment with these elements.

## 4 CONCLUSIONS

The experimental studies showed that with operation on highest modes it is possible to achieve higher energies of accelerated ions in comparison with the nominal energy. In practice, in the main MILAC section the energy of accelerated ions may be inceased from 8.5 to 10 MeV/u without reconstruction with moderate (16%) practically acceptable increase in accelerating field strength.

For the prestripping section it is possible increase energy of particles from 1 to 2.56 MeV/u, therefore, it is achivable only for lighter ions. It is possible to accelerate ions with mass-to-charge ratio of A/q <6 instead of ions with A/q<15 with the same fields.

## 5 REFERENCES

[1]. Bomko V.A., Revutsky E.I. // Zhurnal Tekhnicheskoj Fiziki, 1964, v. 34, No 7, p. 1259-1265.(In Rassian)
[2]. Bomko V.A., Dyachenko A.F., Pipa A.V. et al. //Problems of Atomic Science and Technology. Seriya: Technika Fisicheskogo Experimenta, 1979, v. 1`(3), p. 55-57. (In Rassian)
[3]. Bomko V.A., Rudyak B.I., Kobetz A.F. et al. // Problems of Atomic Science and Technology. Seriya: Jaderno Fisicheskije Issledjvaniya, 1989, v.6 (6), p.23-26. (In Rassian)
[4]. Bomko V.A., Dyachenko A.F., Kobetz A.F. et al. // Nuckl. Instr. And Methods in Phys. Res. A 406, 1998, p. 1-5.
[5]. Bomko V.A., Dyachenko A.F., Pipa A.V. // Problems of Atomic Science and Technology. Seriya: Technika Fisicheskogo Experimenta, 1981, v. 3`93), p. 28-31. (In Rassian)
[6]. Tepliakov V.A., Stepanov V.B. //Radiotecknika i Electronika, 1968, v. 13, No 11, p. 1965-1975. (In Rassian)
[7]. Kapchinsky I.M. //Uspekhi Fizicheskikh Nauk, 1980, v. 132, No 4, p. 639-661. (In Rassian)
[8]. Andreev V.G. // Zhurnal Tekhnicheskoj Fiziki, 1971, v.11, No 4, p.788. (In Rassian)
[9]. Bomko V.A., Kliucharev A.P., Rudyak B.I. //Atomnaya Energiya, 1971, 31,(2), p.123. (In Rassian)
[10]. Bomko V.A., Dyachenko A.F., Kobetz A.F. et al. //Proceed 15 Soveschaniya po Uskoriteliam Zariazennich Tchastic, Protvino 1996, v. 2 h. 54-57 (In Rassian)