# MAGNETIC COUPLED ACCELERATING STRUCTURE

*S.V. Kutsaev[1], N.P. Sobenin[1], A.A. Zavadtsev[2], R.O. Bolgov[1], P.K. Davydov[1]*
*[1]Moscow Engineering Physics Institute, Moscow, Russia;*
*[2]Nano Invest, Reutov, Russia*
*E-mail: s_kutsaev@mail.ru*

This paper presents the results of a survey study that analyzed the possibility of using a magnetic coupled disk-loaded waveguide as an accelerating structure in travelling wave (TW) regime. The electrodynamics parameters of such a structure at various modes in C-band for a wide range of phase velocities as a function of aperture radii and coupling slot sizes are presented. This accelerating structure is applicable for forward or backward wave operation modes. The version of a 10 MeV combined accelerator with a standing wave (SW) coupler and a TW magnetic coupled accelerating structure is proposed.

PACS 29.17.+w, 29.27.Eg

## 1. INTRODUCTION

As one knows, one of the most popular accelerating structures for linear accelerators is a disk-loaded structure (DLS) working on an $E_{01}$ travelling wave (TW) with electric and biperiodical accelerating structure (BAS) working on standing wave (SW) a with magnetic coupling.

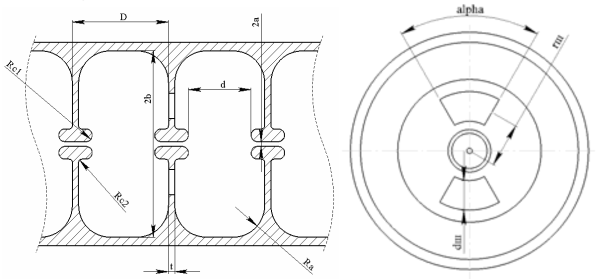


*Fig.1. Magnetic-coupled disk-loaded structure*

The TW magnetic coupled DLS presented at Fig.1 possesses the advantages of both classical DLS (small filling time) and BAS (high shunt impedance and coupling coefficient). As the coupling of such a structure is affected by magnetic field, its dispersion would be negative. This kind of structure would be compactly called a negative dispersion structure (NDS).

Increasing the period D we can achieve working modes higher than π. In this case the dispersion of the structure would be positive again. This kind of structure would be compactly called a positive dispersion structure (PDS) [1,2].

It is of interest to calculate the electrodynamical parameters of these structures (first of all shunt impedance, group velocity and attenuation) as functions of mode and some geometrical dimensions (accelerating gap, aperture and coupling gaps).

## 2. ELECTRODYNAMICAL PARAMETERS

### 2.1. STRUCTURE WITH NEGATIVE DISPERSION

The structures working on modes close to π are perspective to use in linear accelerators with a high acceleration temp. Increasing shunt impedance while having a high coupling coefficient is the general aim of structure optimization.

The resonant model of the NDS designed for 4π/5 mode and electric field distribution are shown at Fig.2. The structure has been tuned to work at 5712 MHz resonant frequency.

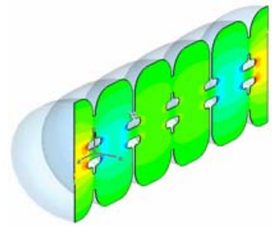

*Fig.2. Resonant model and E-field distribution of 4π/5 mode NDS*

The dependence of principal electrodynamical parameters to phase velocity is presented at Table 1. These results have been obtained for coupling gap span angle 90° and normalized aperture a/λ=0.04.

***Table 1***

*Electrodynamical parameters of the NDS with different phase velocity*

| Phase Velocity | 1.0 | 0.8 | 0.6 | 0.4 |
|---|---|---|---|---|
| Shunt Impedance, MΩ/m | 143 | 132 | 69 | 67 |
| Coupling coefficient, % | 12.0 | 13.7 | 18.0 | 27.3 |
| Attenuation, 1/m | 0.11 | 0.12 | 0.11 | 0.12 |
| Group Velocity, % | -6.1 | -6.5 | -8.0 | -10.5 |

Shunt impedance of this structure appears to be quite high, this is because of a small aperture what is undesirable. Thus, the dependence of these parameters with a respect to aperture size is a question to research. The results are presented in Table 2. The phase velocity is considered to be 1.0 and coupling gap span angle is 75°.

***Table 2***

*Electrodynamical parameters of the NDS with different aperture*

| Normalized aperture | 0.04 | 0.07 | 0.1 | 0.14 |
|---|---|---|---|---|
| Shunt Impedance, MΩ/m | 85 | 73 | 56 | 39 |
| Coupling coefficient, % | 7.7 | 7.3 | 7.2 | 6.6 |
| Attenuation, 1/m | 0.14 | 0.15 | 0.16 | 0.17 |
| Group Velocity, % | -5.9 | -5.7 | -5.5 | -5.4 |

The values of shunt impedance now are comparable to the DLS ones, while the group velocity and coupling coefficient are much higher and could be increased by expanding the coupling gap.

### 2.2. STRUCTURE WITH POSITIVE DISPERSION

For this structure it is interesting to research the dependences of electrodynamical parameters of the geometrical dimensions and operating modes in fact to obtain its optimal performance.



PROBLEMS OF ATOMIC SCIENCE AND TECHNOLOGY. 2010. № 3.
*Series:* Nuclear Physics Investigations (54), p.48-50.

First the aperture size has been varied from 0.04 to 0.14 like in NDS, while the operating mode was considered to be 6π/5, phase velocity 1.0 and other geometrical dimensions were fixed. Another important dependence is of the phase velocity, as the TW buncher consists of different phase velocity cells. The dependence diagram of shunt impedance can be observed on Fig.3, while the one of group velocity is presented on Fig4.

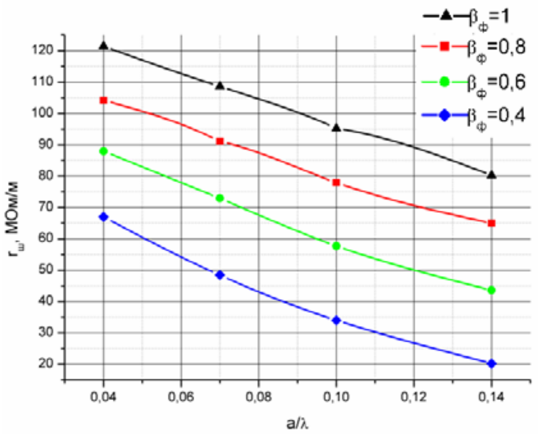


*Fig.3. The dependence of PDS shunt impedance vs aperture size*

Thus, the values of shunt impedance and group velocity are high enough in the whole range of the aperture radius. It is important because this size varies much both in TW buncher and in accelerating part with constant gradient to obtain the necessary field strength.

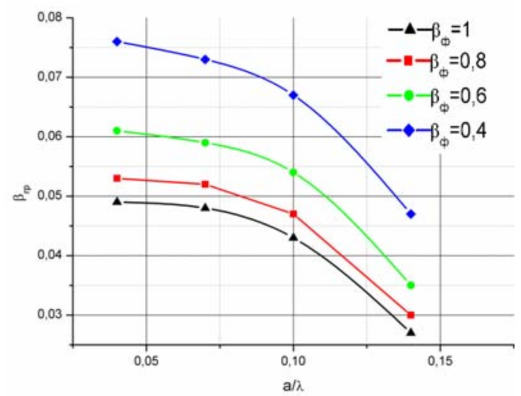


*Fig.4.The dependence of group velocity vs aperture size*

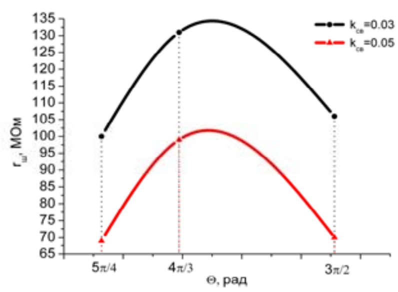


*Fig.5. The dependence of PDS shunt impedance vs operating mode*

Now it is necessary to determine what operating mode is optimal. The dependences of this structure's shunt impedance of an operating mode for the cases of two different coupling coefficients are presented on Fig.5. The normalized aperture size is considered to be 0.1. The maximum of the shunt impedance is achieved on modes near 4π/3.

Comparing the electro dynamical parameters of PDS working on 4π/3 mode, NDS working on 3π/4 and DLS working on classical 2π/3 mode with a/λ =0.1 and the coupling gap span size was chose such to obtain group velocity around 4.5%, we see that PDS has the highest shunt impedance and group velocity. This comparison results are presented in Table 3, where Q stands for quality factor and α for attenuation.

***Table 3***

*Parameters of different TW structures*

| a/λ | Type | $r_{sh}$, MΩ/m | Q | α, 1/m | $\beta_{gr}$, % |
|---|---|---|---|---|---|
| 0.04 | PDS | 173 | 11500 | 0.108 | 4.8 |
| | NDS | 86 | 7400 | 0.145 | 5.9 |
| 0.07 | PDS | 159 | 11500 | 0.116 | 4.5 |
| | NDS | 73 | 7520 | 0.151 | 5.5 |
| 0.10 | PDS | 140 | 11300 | 0. 120 | 4.4 |
| | NDS | 56 | 7130 | 0.156 | 5.7 |
| | DLS | 87 | 9070 | 0.660 | 1.0 |
| 0.12 | PDS | 103 | 9800 | 0. 139 | 4.4 |
| | NDS | 39 | 6710 | 0.173 | 5.4 |
| | DLS | 65 | 9000 | 0.208 | 3.2 |
| 0.14 | PDS | 79 | 8600 | 0.166 | 4.2 |
| | NDS | 39 | 6710 | 0.173 | 5.4 |
| | DLS | 65 | 9000 | 0.208 | 3.2 |

## 3. COMBINED ACCELERATOR

### 3.1. HYBRID STRUCTURE

Consider using PDS as an accelerating structure in electron linac designed for cargo inspection systems. This linac should have an output energy equaled to 10 MeV. To achieve this flexibility the beam loading should be used, thus the output current should be high enough.

Such an accelerator should have the particle capture as high as possible, while being as short as possible. This can be reached by using a hybrid accelerating structure with a 3 cell SW BAS buncher, which allows to achieve high capture on a short length and TW accelerating part. For this accelerator PDS structure working on 4π/3 mode with a/λ= 0.1 has been chosen.

### 3.2. INPUT COUPLER

The RF power is input into the first TW cell. To ensure symmetry of the field in this cell, opposing WR187 waveguides are connected. One of these waveguides is short-circuited by the metal pin and is used for vacuum pumping. Fig.6 shows the model of this coupler as well as the electric field intensity.

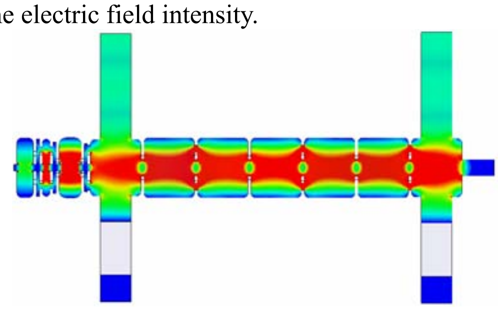

*Fig.6. Input coupler in the hybrid structure*

The SW buncher was considered to be identical to the one used in the SW cargo inspection accelerator. The parameters of the cells are shown in Table 4.

*Table 4*

*SW structure parameters*

| Cell number | Phase velocity | Effective shunt impedance, MΩ/m | Coupling coefficient, % | Q-factor |
|---|---|---|---|---|
| 1 | 0.67 | 50.3 | 38.9 | 5540 |
| 2 | 0.42 | 28.2 | 13.5 | 5680 |
| 3 | 0.78 | 97.6 | 10.9 | 6800 |

The input coupler has been tuned to provide a TW regime in the accelerating part at the 5712 MHz operating frequency. The output cell radius and coupler gap width have been chosen so that a complex electric field on the axis would be equal in the centers of each cell (Fig.7).

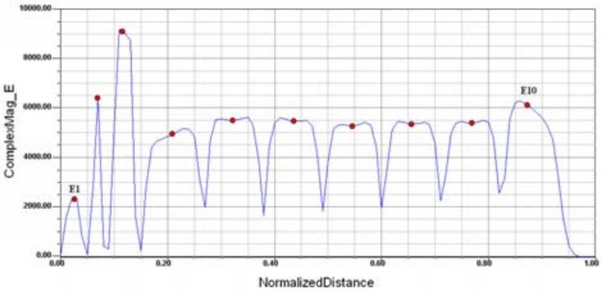


*Fig.7. Complex electrical field distribution on the axis of the structure*

Then, the input cell radius and coupler gap have been tuned so, that there would be no reflection to the input port. The S11 parameter distribution is shown at Fig.8. The peaks near the resonant frequency stand for the resonances excited on the nearest modes.

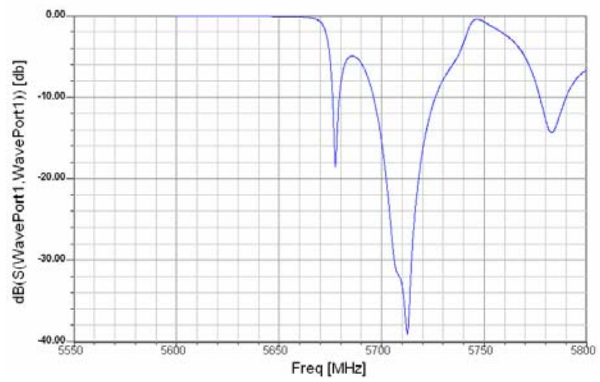


*Fig.8. Frequency characteristic*

### 3.3. ELECTRON DYNAMICS

For this coupler geometry the following distribution of the electric fields normalized to the one in the first TW cell has been achieved.

*Table 5*

*Electric Field Distribution*

| N | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| E/Etw | 0.42 | 0.98 | 1.65 | 0.9 | 1 | 1 | 1 | 1 | 1 | 1.1 |

For this data the dynamics of the electrons in such an accelerator has been calculated with a help of PARMELA and Hellweg codes. The input and output parameters of the accelerator are presented in Table 6.

*Table 6*

*Combined Accelerator Parameters*

| | |
|---|---|
| Input Power, MW | 4.5 |
| Pperating Frequency, MHz | 5712 |
| Number of Cells | 3 + 28 |
| Output Energy, MeV | 10.8 |
| Input Current, mA | 200 |
| Output Current, mA | 135 |
| Capture Coefficient, % | 67.5 |
| Energy Spectrum, % | 4.8 |
| Phase Length, grad | 35 |
| Length, m | 0.98 |

## CONCLUSIONS

The electrodynamics parameters for the magnetic coupled disk loaded structure have been calculated both for positive and negative dispersions for the 5712 MHz.

The possibility of using a PDS in the combined accelerator been considered. The RF input coupler for this accelerator has been developed and tuned. The electron dynamics for this structure has been calculated.

## REFERENCES

1. M. Ferderer, A. Zavadtsev, S. Kutsaev, et al. Accelerating Structure For C-Band Electron Linear Accelerator Optimization // *Proc. LINAC'08*. 2008, p.2746-2749.
2. V. Pirozhenko. Efficient Traveling-Wave Accelerating Structure For Linear Accelerators // *Proc. EPAC'08*. 2008, p.921-923.

*Статья поступила в редакцию 23.09.2009 г.*

## УСКОРЯЮЩАЯ СТРУКТУРА С МАГНИТНОЙ СВЯЗЬЮ МЕЖДУ ЯЧЕЙКАМИ

***С.В. Куцаев, Н.П. Собенин, А.А. Завадцев, Р.О. Болгов, П.К. Давыдов***

Приведены электродинамические характеристики круглого диафрагмированного волновода с магнитной связью в СВЧ-диапазоне на разных видах колебаний и разных значениях фазовой скорости волны в функции радиуса апертуры и размеров щелей связи. Ускоряющая структура такого типа может работать в режиме прямой или обратной волны. Рассмотрен вариант комбинированного ускорителя на энергию 10 МэВ с группирователем, работающим в режиме стоячей волны, и ускоряющей частью на основе структуры с магнитной связью с положительной дисперсией.

## ПРИСКОРЮЮЧА СТРУКТУРА З МАГНІТНИМ ЗВ'ЯЗКОМ МІЖ КОМІРКАМИ

***С.В. Куцаєв, Н.П. Собєнін, А.А. Завадцев, Р.О. Болгов, П.К. Давидов***

Наведено електродинамічні характеристики круглого діафрагмованого хвилеводу з магнітним зв'язком в СВЧ-діапазоні на різних видах коливань і різних значеннях фазової швидкості хвилі у функції радіусу апертури і розмірів щілин зв'язку. Прискорююча структура такого типу може працювати в режимі прямої або зворотної хвилі. Розглянуто варіант комбінованого прискорювача на енергію 10 МеВ з групувачем, що працює в режимі стоячій хвилі, і прискорюючою частиною на основі структури з магнітним зв'язком з позитивною дисперсією.