MULTIPLE BEAM COUPLED CAVITY MICROWAVE PERIODIC STRUCTURE[1]

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Abstract

Concept of parallel electrical circuit was applied to microwave structures and resulted in multibeam or quasi-hollow beam structure (MBS) concept [1]. The proposed concept allows to modify magnetically or electrically coupled periodic microwave structure into the proposed multibeam or hollow beam structure and can be used for any charged particles. Concept analysis and some results were presented at EPAC96 conference. A prototype with four beams - four beam structure (FBS) based on a side coupled structure has been studied both theoretically and experimentally [2]. A number of applications is expected for this concept. It permits to transmit higher beam current in multiple beams compared to a single beam current which is restricted due to space charge limitations, especially at higher frequency. First prototype of the designed FBS is built in X-band. 10 cm long electron beam head is designed for 1.2 MeV electron energy, 1 A total electron beam current and 1 kW average beam power. Various applications in microwave tube technique are studied.

Introduction

An idea of building microwave linear accelerators in a frequency range close to and beyond 10 GHz has lately become very popular both for high energy and portable accelerators. However, difficulties of this "state-of-the-art" technique such as manufacturing and tuning of microwave cavities become much more complicated at 10 GHz and higher compared to S and L band.

Operating at higher frequency permits a reduction in outline dimensions and weight of the final package. However, in higher frequency ranges one faces a problem of beam current restriction among a number of other complications. Beam current is restricted by physical aperture size due to space charge limitation and, in commonly used structures, it is difficult to exceed this limitation of approximately 10^9 1/cm^3 without affecting structure efficiency and energy gain.

Multiple Beam Concept and Structure

Multiple or hollow beam concept for microwave structure design is proposed [1] to expand range of beam current which could propagate through the structure. Exaple of MBS design is shown in Fig.1, 2. MBS permits exceeding the space charge limitations due to reduction of aperture size at high frequency observed, for example, in X-band.

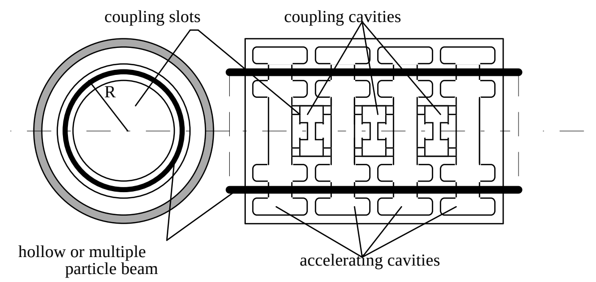

Fig.1. Magnetically Coupled MBS.

Beam cross section at radius R is shown as quasi-continuous, though it could be built of multiple small apertures.

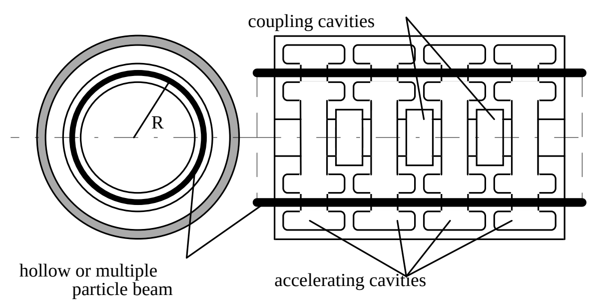

Fig. 2. Electrically Coupled MBS.

The proposed structure could also be used to increase energy gain for the same linac length in a mode of multiple pass operation.

Energy gain will be increased in proportion to $N^{1/2}$, where N is number of beam passes, assuming that we use the same power source and structure volume grows proportionally to N. Therefore, with four passes, energy gain would be two times higher, with 16 - four times higher, etc. Bending magnets could be used to bend the beam 180 degrees.

Potential application of the proposed concept and the corresponding variations of structure design could be found in many areas where accelerators are used. We can foresee various commercial applications, such as non-destructive testing, sterilization, etc. Concept could be applied to design of microwave amplifier tubes. Hollow beam instabilities have been studied and observed by Kyhl and Webster at low

[1] - work was supported by Department of Energy, SBIR grant FG03-95ER82065

energies (<100 keV) for TWT[3] applied to traditional structures with beam concentrated in the center. One of the ideas, expressed in the accelerator physics community is to develop a "table-top" FEL for commercial applications with an acceptable price range. X-band accelerator for 9 - 13 MeV is a potential source for that application. The proposed system seems also to be attractive for devices using beam-beam interaction.

The coupled circuits model and microwave theory was used to analyze one of the simple realizations of the proposed concept. An FBS cavity was designed which is capable of accelerating four parallel beams, the tuning procedure was refined and microwave properties of the structure were studied. The study could be considered successful as our analysis confirmed predictions made at the very early stage of development.

Study of Four Beam Structure (FBS)

Theoretical Analysis and Coupled Circuit Model

To study MBS properties, we decided to start with a simlified version of FBS resonator [2]. The resonator is shown in Fig.3. Two "rings" of four cavities, coupled through a central coupling cavity have formed the complete resonator.

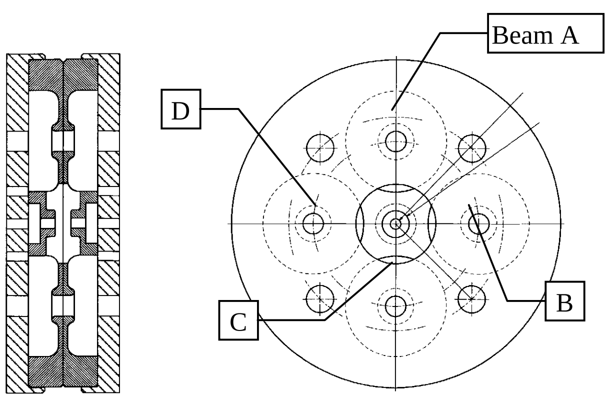

Fig.3. One-period FBS Resonator Analyzed By Means of Coupled Circuit Model.

Schematic for two rings of coupled half cells, coupled together through a single coupling resonator is illustrated in Fig.4. This element represents a period of the four-beam accelerator structure. The modes of resonantly coupled, multibeam structure were analyzed by establishing the notation and normalization for the simple structure so that the impedance matrix of the more complicated multibeam structure can be written by inspection.

The analysis shows that the structure behaves like a normal biperiodic coupled-cavity linac structure with coupling factor k_1 , with the addition of the non-propagating modes due to the internal resonances of the multiple gap accelerating cells.

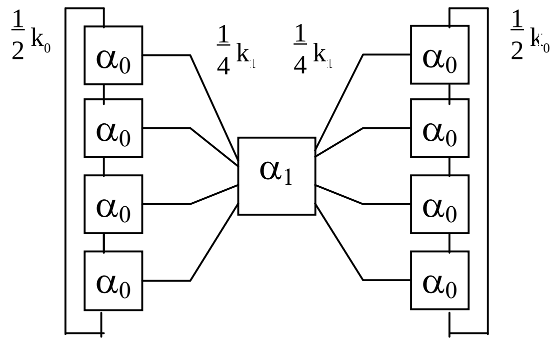

Fig. 4. Schematic representation of two "rings" of FBS cavities coupled through a single coupling cavity.

Since the internal modes don't propagate only if the cells and coupling apertures are perfectly symmetrical, the coupling factor k_0 should be kept large to keep the internal modes away from the operating frequency to reduce the likelihood of coupling microwave energy to these modes.

Experimental Verification

Test resonator was made by combining the cells, shown on Fig.5.

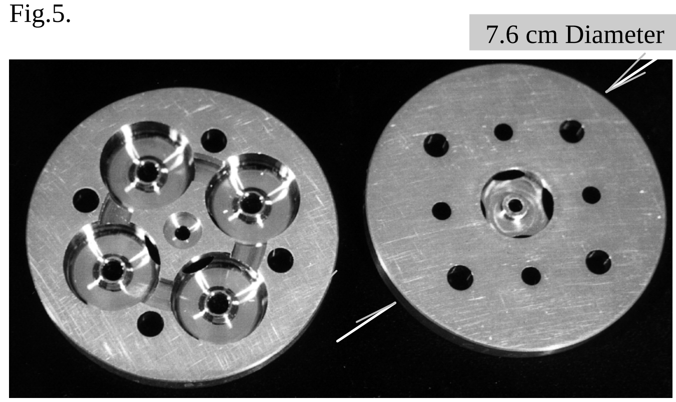

Fig.5. Manufactured X-band Cavity

Coupling between the cavities in the rings was introduced and changed during the measurements to study theoretical predictions, which were in a good agreement with experimental results. We found that the structure behaves like a conventional biperiodic structure with multiple resonant frequencies which correspond to the case of unexcited coupling cavity. Each of this frequencies represent various modes for single "ring " of four resonators. Detailed analysis of the experimental results was provided earlier [2].

Four Beam 1.2 MeV Linac Head

Presently, we plan is to build a working prototype which will deliver 1.2 MeV electron beam at 1 A current in four beams in 12 cm long X-band structure, using the studied FBS (Fig. 5). The goal is to achieve 1 kW average power stored in four beams at 0.001 duty factor and 70 percent beam efficiency. Comparative view of 6 MeV single beam side coupled structure designed for MINAC accelerator and the proposed 1.2 MeV four beam linac and is shown in Fig.6. Dimensions are shown in millimeters.

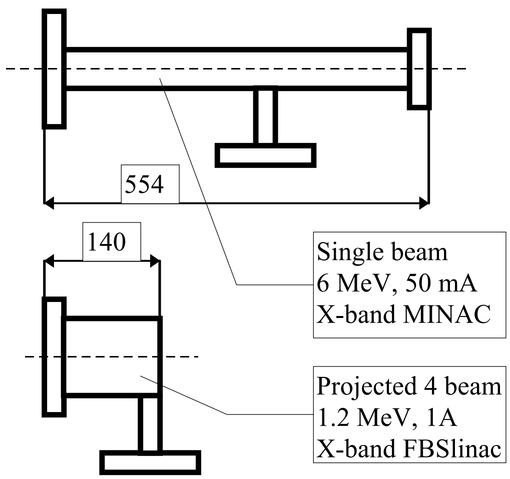

Fig. 6. Comparative view of two structures

Length of FBS linac, which is approximately equal to L_{minac6} /4, where L_{minac6} is,obviously, length of MINAC-6. The latter is designed for energy of 6 MeV. The improved version utilizes a shorter section and delivers 5 MeV electron beam with beam current of approximately 100 mA. As RF length L_{minac5} equals 40 cm, corresponding RF length of a projected FBS approximately 10 cm.

Calculated and experimental load lines for MINAC-5 were in a very good agreement. The maximum current transported through the section is 110 mA. This is a maximum value which we were able to achieve in X-band linac using magnetron as a power source.

If the proposed FBS linac would have similar characteristics and four accelerated beams, simple considerations tell us that using four times higher power magnetron (6 MW), beam current would be 440 mA at the same energy of 6 MeV.

In FBS, we expect to increase beam efficiency to about 60 to 70% and have 1 A at 1.2 MeV with the same magnetron power (1.5 MW CTL1100).

Load line and efficiency for the proposed FBS is shown on Fig. 7. Maximum energy is about 1.8 MeV, and efficiency reaches its maximum at approximately 1.5 A beam current.

Beam dynamic analysis for the FBS short segment has been made using PARMELA computer code. It shows that no focusing is required for the electron beam in order to propagate down the structure.

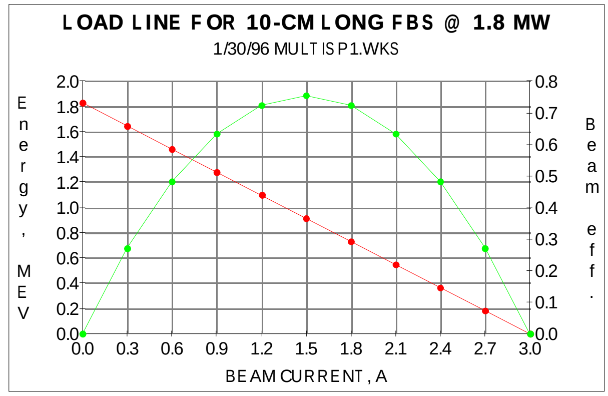

Fig. 7. Load Line for 10 cm long at 1.8 MW RF power.

Conclusion

FBS was studied as an example of MBS concept, described in [1,2]. The proposed technical study appears to be successful and might help to solve the problem of beam current limitation or increase energy gain by using mulripass operating mode. The proposed concept seems to be a new technical approach in accelerator structure construction and has a number of various practical realizations. The concept could be used for e-beam processing, high energy radiography, computer tomography, and other applications. It does not seem possible to have every proposed design studied in details in a reasonable period of time. However, we are hoping to continue our study of various types of the proposed structure design. Potential application of the proposed structure could be found in many areas where accelerators are used.

This article concludes an analysis made during the first stage of a study conducted in order to introduce the multibeams structure design. We have proposed a "turn-key" prototype linac using a miniature 12 cm long FBS and a 1.5 MW X-band magnetron as a power source. Performance goal for the electron beam head is to operate at beam energy of 1.2 MeV and beam peak current of 1 A with no external focusing, providing, therefore, around 1 kW average power stored in four beams at 0.001 duty factor.

References

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