A new RF structure: bent-vane type RFQ

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Abstract. A new RFQ accelerator cavity structure with bent vanes is proposed to meet the miniaturization requirement of low frequency accelerators. The new structure has a downsized cross section by bending the vanes while maintaining a certain vane length. It also possesses the advantage of a simple cooling configuration. The new RFQ structure is presented in this paper.

1. Introduction

Radio frequency quadrupole (RFQ) can accelerate, focus, and bunch the particle beam in the low energy field, and is generally used as an injector for the high energy accelerator. Four-rod type and four-vane type are the main RFQ accelerator structures. A four-rod RFQ is generally used at low frequencies (below about 200 MHz), while a four-vane RFQ is used at high frequencies (above about 200 MHz) [1]. However, the cooling structure of a four-rod RFQ is quite complex, so it is difficult to design and machine the cavity, while a four-vane RFQ is large in the lateral dimension in the low frequency band (below about 100 MHz) which increases the machining difficulty and cost [2]. In addition, a four-vane RFQ with windows can decrease the cross section in the low frequency band, but its cooling structure is extremely complicated, and the windows can directly influence the mechanical strength of the cavity and the electric field flatness [3].

To overcome the disadvantages of the three kinds of RFQ accelerators described above, a new RFQ structure is proposed called the bent-vane type RFQ at the Institute of Modern Physics (IMP), Chinese Academy of Sciences. It significantly reduces the cross section of cavity at low frequencies, and has a simple water-cooled structure. The RF structure of the bent-vane RFQ is presented in this paper.

2. Theoretical foundation

Considering an ideal four-vane RFQ with a cloverleaf geometry (figure 1), its equivalent circuit is shown in figure 2 [1]. According to the equivalent circuit, the cavity quadrant radius is

\[
r^2 = \frac{16}{\mu_0(4+3\pi)\omega_0^2C'}
\]

where \(\omega_0\) is the resonant frequency, \(C'\) is the total capacitance per unit length and \(\mu_0\) is the permeability constant. This equation indicates that the lateral dimension can be decreased by increasing the capacitance at a fixed frequency.
Based on the discussion above, the vanes of the four-vane RFQ can be bent to increase the capacitance, thus reducing the lateral dimension of the cavity. Hence, a new RFQ structure is proposed called the bent-vane type RFQ, shown in figure 3.

3. RF structure
To obtain a suitable lateral dimension and quality factor for the bent-vane RFQ, the cross section profile was parameterized with 13 independent variables, shown in figure 4. The RF structure of the bent-vane RFQ is optimized using the CST MWS [4].
$r_0$, $\rho$ and $\alpha_1$ are defined in the code RFQGen [5]. The other parameters can be optimized by ourselves using CST MWS. Keeping frequency constant (81.25 MHz), it is explored that the other ten parameters have an impact on the lateral dimension ($L$), quality factor and shunt impedance of cavity, shown in figure 5 (only presenting four parameters). Taking into account the impact of various parameters on the $L$, quality factor and shunt impedance and the feasibility of actual machining processing, the optimization values of the parameters of cross section are listed in Table 1. For example, the $L_1$ can be not chosen $\leq$ 8 mm, on the one hand, the vane modulation must choose $L_1 \geq$ 8 mm in the actual machining processing, on the other hand, quality factor and shunt impedance have the maximum values at 10 mm according to the figure 5 and its redundancy is 2 mm.

**Table 1.** The cross section parameters of bent-vane RFQ.

| Parameter | Value   | Parameter | Value   |
|-----------|---------|-----------|---------|
| $r_0$     | 5.347 mm| $L$       | 279 mm  |
| $\rho$    | 0.75    | $R_v$     | 20 mm   |
| $\alpha_1$| 10 Deg. | $\alpha_2$| 5 Deg.  |
| $L_1$     | 10 mm   | $R_w$     | 40 mm   |
| $L_2$     | 5 mm    | $L_4$     | 10 mm   |
| $R_{b1}$  | 5 mm    | $R_{b2}$  | 5 mm    |
| $L_3$     | 10 mm   |           |         |

A traditional four-vane RFQ is optimized to compare with the bent-vane RFQ. The cross section of the traditional four-vane RFQ and bent-vane RFQ are compared in figure 6. The cross section of the bent-vane RFQ is 94.5 mm smaller than the four-vane RFQ.
Figure 5. The variation of the lateral dimension, quality factor and shunt impedance of bent-vane RFQ as the functions of the parameters of cross section profile. (only presenting four parameters)

Figure 6. The comparison of RF structure of the traditional four-vane RFQ and bent-vane RFQ.
4. Cooling structure
The bent-vane RFQ has a very simple cooling structure, shown in figure 7. It is easy for factory to machine cooling structure.

![Cooling structure of the bent-vane RFQ](image)

**Figure 7.** The cooling structure of the bent-vane RFQ.

5. Conclusions
A new RF structure of RFQ accelerator is proposed called the bent-vane type RFQ. The bent-vane RFQ can downsize cross section and has the simple cooling structure. The cross section profile is defined with 13 independent variables. With parameters optimization, the cross section is reduced 94.5 mm compared with the four-vane RFQ. The cooling structure is very simple for factory to machine it.

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References
[1] Wangler P T 2008 *RF Linear Accelerators* (New York: John Wiley&Sons)
[2] Yang L and Lu L 2018 *Proceedings of the 29th Linear Accelerator Conference (Beijing)* paper THPO050
[3] Ostroumov N P and Kolomiets A A 2002 *Physical Review Special Topics - Accelerators and Beams* **5** 060101
[4] CST Simulation Packages [http://www.cst.com/](http://www.cst.com/)
[5] Crandall R K 2005 *RFQ Design Codes*