Design and Optimization of Non-linear Tapers for High Power Gyrotrons

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Abstract

Abstract. *In this paper, the design and optimization of non-linear taper connecting the output section of the cavity resonator to the uniform waveguide section for high power gyrotrons is presented. The design of a non-linear taper of a 42 GHz, 200 kW CW gyrotrons operating in the* $TE_{0,3}$ *mode with axial output collection has been taken as a case study. The taper synthesis has been carried out using conventional taper design procedures and analysis is carried out using a dedicated scattering matrix code. In addition, an improved particle swarm optimization – an evolutionary optimization algorithm – is presented and used for the design optimization of non-linear taper.*

I. Introduction

Gyrotron output system consists of an output taper which connects the interaction region with the main waveguide system, a quasi-optical mode converter, and the RF window [1]. The requirement of a taper in gyrotrons is good match with the suppression of spurious modes. Various taper designs [2] such as exponential taper, triangular taper, Klopfenstein taper can be employed for matching purpose. In this work, we have used a raised cosine taper profile as it yields less mode conversion than the Klopfenstein profile or an exponential tape [3]. The design and optimization of raised cosine nonlinear taper is carried out for a specific 42GHz, 200kW, CW Gyrotron operating in the $TE_{0,3}$ mode with axial output collection. The scattering matrix method is very fast and accurate for taper analysis. In this work, the analysis of the taper was carried out using a dedicated scattering matrix code [4]. Particle Swarm Optimization (PSO), developed by Kennedy and Eberhart [5] is a simple, effective and promising method used for search and optimization in multidimensional feature space. The feasibility of simple PSO is illustrated in [6] for high-power microwaves control applications. In this paper, an improved particle swarm optimization method is presented and used for the design of non-linear tapers.

II. Particle swarm optimization

Particle swarm optimization (PSO) is a population based stochastic optimization technique developed by Eberhart and Kennedy [5]. In this algorithm, group of potential solutions, known as *particles* are flown through the search space in order to get optimum solution. The i^{th} particle in the *swarm* (a population of particles) is represented as $X_i = (x_{i1}, x_{i2}, \ldots, x_{iD})$, and its velocity is given by $V_i = (v_{i1}, v_{i2}, \ldots, v_{iD})$. The best previous position of each particle is given as $P_i = (p_{i1}, p_{i2}, \ldots, p_{iD})$. The best particle among all particles is represented by symbol *'g'*. The velocity and position of each particle is updated using following relations:

$$v_{id} = w * v_{id} + c_1 * rand() * (p_{id} - x_{id}) + c_2 * rand() * (p_{gd}, x_{id}), \quad (1a)$$

$$x_{id} = x_{id} + v_{id} \quad (1b)$$

where c_1 (cognitive constant) and c_2 (social constant) are two positive constants, rand() is a function to generate random number between 0 and 1, and w represents inertia weight which is used to control between local and global search.

The ability of PSO in exploring global optima is much dependent on the choice of parameters such as c_1, c_2 , w, and V_{max}. Various experiments for the selection of optimum parameters are demonstrated in [7]. In our experiment, linearly decreasing inertia weight (w) as proposed in [8] is used. The maximum velocity in each dimension is also restricted to $V_{max}= 0.25 \cdot X_{max}$. The value of cognitive acceleration constant (c_1) and social acceleration constant (c_2) are fixed at 2.0 which are suggested as best in most experiments. In this paper, we have experimented PSO with 10 and 30 population sizes for 100 and 300 iterations respectively.

An improved PSO algorithm for constrained optimization is used in this work. The algorithm is the modification of the algorithm presented by Hu and Eberhart [9] for handling constraints efficiently. It includes 3 modifications: dynamic initializations particles and velocity both within specific range, penalty based approach for constraints handling and imposing restrictions to bound constraints by the range of range of parameters. The advantage of the proposed modifications is that the initialized particles need not satisfy all the constraints, thus making the algorithm easy work and efficient to handle design constraints. The proposed algorithm used is shown in Fig. 1 with the modification highlighted.

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Algorithm: Improved PSO for Constrained Optimization
Initialization:
Initialize Parameters c1, c2, w, and Vmax= γ · Xmax
For each particle in the swarm{
   Initialize particles (X) randomly in the range [Xmin, Xmax]
   Initialize velocity of particles (V) randomly in the range [-Vmax, Vmax]
}
Evolution:
Do{
   For each particle{
      Calculate the fitness value and modify the fitness according to violation of constraints
      If the modified fitness value is better than the best fitness value (pBest) in history, set current value as
          the new pBest.
   }
   Choose the particle with the best fitness value of all the particles as the gBest
   For each particle{
      Calculate particle velocity according to equation (1a)
      Restrict the velocity of particles by [-Vmax, Vmax]
      Update particle's position according to equation (1b)
      Restrict the particle's position by [Xmin, Xmax]
   }
}While maximum iteration or minimum error criteria is not attained
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Figure 1. Improved Particle swarm optimization algorithm for constrained optimization.

III. Experiment

In this paper, the design of raised cosine taper for 42 GHz, 200 kW, CW gyrotrons is performed. We consider four design parameters of the nonlinear taper namely – length of taper (L), radius of taper at output end (r_2), number of sections (n), and gamma (γ) while keeping radius of taper at input end (r_1) constant. The range of design parameters considered for the design are mentioned in Table 1. The objective for the design considered was to obtain maximum transmission coefficient (i.e. s21-parameter).

Design parameter	Range
Length (L)	200~350 mm
Radius at output end (r_2)	35~45 mm
Number of sections (n)	50~500
Gamma (γ)	0.1~1.0

Table 1: Range of design parameters

The optimization for the design parameters was carried out using improved PSO as presented in previous section with swarm size 30 for 300 iterations. We have also observed the effects of varying gamma parameter and radius at the output end of the taper (a2) on the transmission coefficient. The effect of parameter gamma (γ) on the taper synthesis and transmission coefficient is shown in Fig. 2, while the effect of radius (at output end) on the taper synthesis and transmission coefficient is shown in Fig. 3. A transmission coefficient of 99.86 was obtained using optimized design parameters. The optimized taper was obtained with length 310.67 mm, output end radius of 35 mm, with 382 no. of sections, and 0.527 value of gamma parameter.

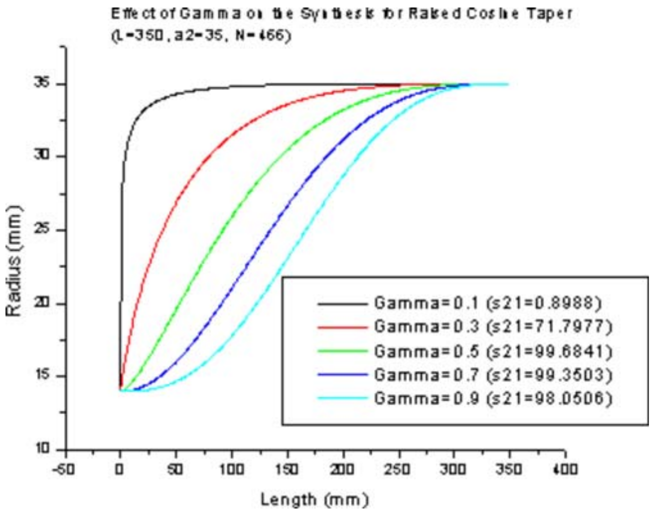

Figure 2. Effect of gamma parameter on the synthesis of raised cosine taper

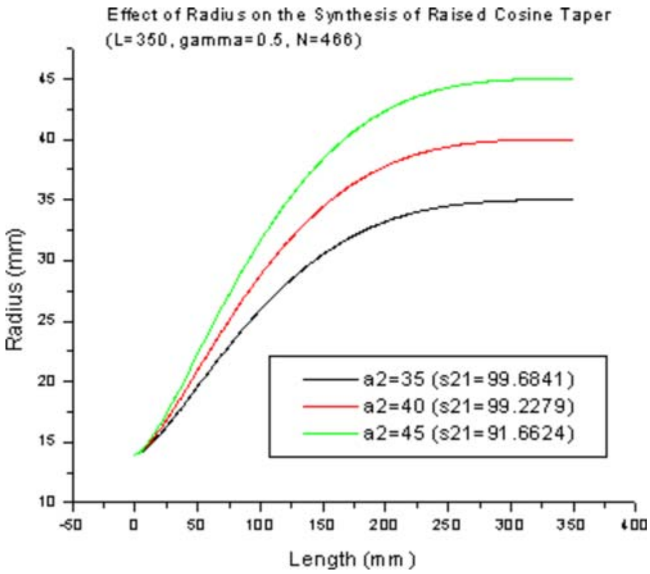

Figure 3. Effect of radius (r_2) on the synthesis of raised cosine taper

IV. Conclusions

An improved particle swarm optimization algorithm is presented and used for the design of raised cosine non-linear taper for specific high power gyrotrons. A dedicated scattering matrix code was used for the fast and accurate analysis of taper during design process. The selection of PSO parameters was carried out in accordance with previous experimental investigations. The optimized results show the best matching obtained with the taper which shows effectiveness of the method. The time required for the optimization was 30 minutes approximately.

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