THE COST OPTIMIZATION STUDIES OF THE SUPERCONDUCTING LINAC*

Y. Tao^{a,b}, Z.J. Wang^a, Y. He^{a,*}, S.H. Liu^a, W.S. Wang^a, C. Feng^a, P.Y. Jiang^a, H. Jia^a, W.L. Chen^{a,b} ^aInstitute of Modern Physics, the Chinese Academy of Sciences, Lanzhou 73000, China ^bUniversity of the Chinese Academy of Sciences, Beijing 100049, China

Abstract

The research superconducting linac is growing in energy and power which induces an increase of the project cost. The RF cavities and RF power supplies mainly contributes the cost of the superconducting linac, which is a competitive technology for high power machine. A code internally with optimization algorithm is developed to optimize the geometric beta value of superconducting cavity family and transition energy to increase the acceleration efficiency of the whole linac. In this paper, the CADS Linac is taken as example to demonstrate the design procedure and the preliminary results of the CADS linac is also presented. The new method can be also used in other high power superconducting facilities.

INTRODUCTION

The applications of the research accelerator are becoming more and more diverse, from the very low power medical accelerators to the high power driven subcritical accelerators. One of the main advantages of the linear accelerator is its capability for producing highenergy and high-intensity charged-particle beams with high beam quality, where high beam quality can be related to a capacity for producing a small beam diameter and small energy spread, which make it widely used sufficient to resolve problems. With the development of superconducting RF technology, the high energy high intensity superconducting linac is becoming more and more popular. The main superconducting linac projects all over the world are shown in the Fig.1. From the Fig.1, the beam power of the existed projects is round 1 MW, while for the further planned projects, the beam power will be ten times higher. The huge cost of the superconducting linac has been a factor, which is limit to the development of the linac. However, for the time being the accelerator optimization is concentrated on optimizing the lattice; the linac is merely matching the beam to transport line. It is necessary to find a new method to optimize the cost of superconducting linac.

The China Accelerator Driven Sub-critical System (CADS) [1] which aim to solve the nuclear waste problem is a 1.5 GeV and 10 mA continue wave superconducting linac project consists of two injectors and a main superconducting linac. The CADS roadmap is shown in the Fig. 2. The beam power will reach 10-15 MW. There will be more than two hundred of superconducting

cavities and 20-25 MW RF power need for the whole project. Increasing the acceleration efficiency and utility of RF power is necessary and essential for the project cost optimization.

In this paper, the optimization concept as well as optimization procedures are presented in detail.



Figure 1: The superconducting linac in the world.



Figure 2: The roadmap of CADS project.

THE FOUNDATION OF PHYSICS

To select a reasonable geometric beta and transition energy is of great importance for the superconducting linac since an over specified value which will not be reached will result to a linac reduce the cost. How to choose the geometric beta and transition energy is an optimized problem, and the optimization result cannot be easily found by using the traditional method. As few papers studying the cost optimization of the superconducting linac [2], the new method which using a

^{*}Work supported by IMP

^{*}hey@impcas.ac.cn

code and choosing normalized transit time factor (TTF) and cavity number as objectives is presented.

All of these parameters dependents on each other, the optimization has to be performed in the 2 dimensional space. The energy gain of each cavity is defined as:

$$\Delta W_i = q V_0 \cos(\phi_i), \qquad (1)$$

where q is charge of the particles respectively, ϕ_i is the synchronous phase, and V₀ the efficient voltage that could be written down as :

$$V_0 = \frac{E_{acc} \Box L_i}{T_i}, \qquad (2)$$

where E_{acc} is the max accelerating gradient, L_i is the cavity length and T_i is the TTF. Some of these parameters are functions of other parameters. The length of the cavity is a function of the gap number of the cavity N_{cell} , geometric beta of the cavity βg and wavelength of high frequency electric field λ_i . The cell length measured from the centre of one drift tube to the centre of the next. The equation for the length for this case becomes:

$$L_i = N_{cell} \begin{bmatrix} \beta_{gi} \lambda_i \\ 2 \end{bmatrix}, \qquad (3)$$

The TTF of cavities operating on π -mode of electromagnetic oscillations which is the case for practically all known types of superconducting cavities [3]:

$$T_{c}(N,\beta,\beta_{g}) = \begin{cases} (\frac{\beta}{\beta_{g}})^{2} \cos(\frac{\pi N}{2\beta/\beta_{g}}) \frac{(-1)^{(N-1)/2}}{N((\beta/\beta_{g})^{2}-1)}, (4) \\ \frac{\pi}{4} \\ T_{s}(N,\beta,\beta_{g}) = \begin{cases} (\frac{\beta}{\beta_{g}})^{2} \sin(\frac{\pi N}{2\beta/\beta_{g}}) \frac{(-1)^{(N+1)/2}}{N((\beta/\beta_{g})^{2}-1)}, (5) \\ \frac{\pi}{4} \end{cases}$$

where T_c is for the odd number of cells N in the cavity and T_s is for the even.

For the superconducting cavity, there is a relationship between the peak electric surface field E_{peak} and acceleration field E_{acc} [4]. Consulted a number of papers, the date which consists of lots of E_{peak}/E_{acc} value is from research accelerator project all over the world, such as CADS, ESS, and SPIRAL-2 and so on. The red line in Fig. 3 is plotted using [5]:

$$E_{acc} = \frac{E_{peak}}{k_1 * \exp(-\beta_g / k_2) + k_3},$$
 (6)

By fitting, values of k_1 , k_2 and k_3 constants will be found. For the optimistic case, $k_1=14.45$, $k_2=3.68$, $k_3=-9.13$.

The cavity number and TTF which are not good consistency for each other are factors that used to weigh the cost of the superconducting linac against the power it will bring. The totals of cavity number N_c which depends on the output energy 1.5 GeV are shown in Eq. (7). As

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synchronous phase ϕ_s is a constant, there is an only one affecting factor V₀ which shows radio of the applied power to the maximum power means TTF influence the cost. In order to choose the right geometric beta and right transition energy, the study of the factors is necessary.

$$N_c = \frac{1.5GeV}{V_0 \cos(\phi_s)} \tag{7}$$



Figure 3: Ratio of the peak electric surface field to accelerating field vs geometric beta.

OPTIZATION OF CADS LINAC

Particle Swarm Optimization (PSO) [6] is relatively new swarm intelligence based heuristic global optimization technique. It seems with the other technique, also based on the concept of population and evolution, through cooperation and competition with other particle to find the global optimal solution.

The accelerating efficiency of the cavity, TTF, is a parameter that shows the ratio of the max accelerating. The accelerated particles are formed in stable bunches. When the particle inject speed is matching with the cavity speed, the max accelerating wave will be created. To come true these ideas, the optimization is provided by an appropriate choice of the objective normalized TTF and cavity number to optimize the geometric beta and transition energy to reduce the cost. The normalized TTF means the TTF of the cavities closely to the max TTF, defined as:

$$F = \sum_{j=1}^{S} \sum_{i=1}^{N} (T_i - T_{\max})^2 / S , \qquad (8)$$

where S is cavity section, N is each cavity number, T_i is cavity TTF and T_{max} is max TTF of each cavity type.

THE PRELIMINARY STUDIES

As the optimization has long time to go, in order to verify the method combining design with optimize, using the method to design the CADS demo facility from 2.1 MeV to 250 MeV. The Fig. 4 shows the results of the optimization of cavity number. There are no good results, because cavity number and TTF are not accord with the physics. The cavity number, which measured for the efficiency of the cavity, is least when the TTF is very high. But in fact, from the results, it is on the contrary.



Figure 4: The cavity number optimization results.

The other result which choice of the normalized TTF as objective is to choosing the right geometric beta and the right transition energy in main linac of CADS to improves the average transit time factor, and therefore the acceleration efficiency of the linac. Figure 5 shows the results of the geometric beta and transition energy choose.



Figure 5: The geometric beta and transition energy results.

To gain the maximum acceleration efficiency this transition should happen when the accelerating efficiency of the normal conducting linac reaches that of the following superconducting linac. But the third and fourth transition energy is disconnected. Two objectives cavity number and normalized TTF cannot separate.

CONCLUSION

The objectives are essential for optimization problem. The preliminary results have been obtained from the previous work. The objectives are modified for time to get more and more reasonable. The multi-optimization objections included normalized TTF and cavity number has been figured out and the optimization process is ongoing.

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REFERENCES

- Z.H. Li, P. Cheng, H.P. Geng, et al., Physics design of an accelerator for an accelerator-driven subcritical system, Phys. Rev. ST Accel. Beams, 16, 080101 (2013).
- [2] M. Eshraqi, cost optimized design of high power linac, in proc. LINAC 2014.
- [3] P N Ostroumov, Physics design of the 8 GeV Hminus linac, New Journal of Physics 8 (2006) 281.
- [4] P. Pierini, Analysis of gradients for proton linac, Gradients and Betas for ESS LINAC, Lund, September 2010, Sweden.
- [5] M. Eshraqi, The Optimization of ESS Superconducting LINAC, ESS AD Technical Note/AD/0010, 21 March, 2011.
- [6] Carlos A. Coello Coello, Member, Handling Multiple Objectives With Particle Swarm Optimization, IEEE, VOL. 8, NO. 3, JUNE 2004.