COMPARATIVE ANALYSIS OF BLADE TUNER OPTIMIZATION OPTIONS FOR THE ILC

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Abstract

Following the successful experience of the blade tuner concept for superconducting cavities, a full parametric analysis has been performed for ILC cost optimization. Different design details have been reconsidered and optimized on the basis of their impact on the ILC requirements and on production costs. Two different designs have been then developed for two options of fabrication material: titanium or stainless steel. The realization of two prototypes, one for each type, has been recently launched for the designs qualifications and comparison. In this paper we discuss the optimization rationales and the expected differences in cost and tuner integration and performances. Cold tests on cavities will be at the basis of the final choice for the ILC.

INTRODUCTION

For the ILC project more than 16000 coaxial tuner are required. The effort to optimize its design is widely justified by the subsequent enormous cost saving. Moreover the actual blade tuner version, although proved to fulfil the slow tuning requirements [1,2], it is far from being in the final design stage and some modifications are required in order to improve its reliability and reduce its total cost.

Two aspects have been considered in the optimization process here presented: first of all a whole design refinement of rings and blades has been performed. This has been obtained taking into account both the geometry and the material of the blade tuner, allowing to develop an unique geometrical solution that can be realized with the rings in titanium or stainless steel. This is very important in view of a possible future use of a steel helium tank when the technology will allow solving the problems in welding titanium to stainless steel. The second aspect considered concerns a major simplification of the driving mechanism and the moving of the motor from a central to a lateral position, thus freeing some space in correspondence of the invar rod of the ILC cryomodule.

The effectiveness of this solution has been proved by means of experimental tests and numerical simulations.

REVIEW OF THE TUNER DESIGN

The tuner review started from these considerations:

- the cost of materials (Ti) is steeply increasing;
- the cavity stability should have positive benefits from a lighter and more compact tuner design;
- the tuner strength and stiffness characteristics should be commensurate to the action on the helium tank and to the total stiffness of parts near the cavity.

By maintaining the original layout of the blade tuner [3-5] that assures a well symmetric behaviour, we optimized all the aspects, from the less relevant to the more important like the blades geometry and their distribution. The design of the optimized blade geometry has been driven by the following constraints:

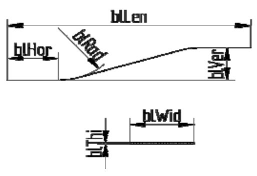
- low cycle fatigue phenomena in the blades and a not reproducible tuner behaviour are unacceptable, therefore **no plasticity** has to occur in the blades in working conditions;
- the maximum **axial load** on the tuner occurs when the helium tank is under vacuum, and outside there is the atmospheric pressure. This compression force is equal to 4155 N;
- the reduction of the number of welds and machining steps leads to a total **cost reduction**.

Keeping in mind these constraints and the necessity to have at least the same tuning capabilities, different blade configurations have been analyzed: they have different materials and geometry, as reported in table 1 and table 2.

Table 1: Blade configurations taken into account

Combination	Geometry	Material
A	Original	TiGr5
B	Original	AISI 316
C	New	TiGr5
D	New	AISI 316
E	New thin	AISI 316
F	New	INCONEL 718

Table 2: different blade geometries considered

	Geometry	blHor	blCla	blVer	blLen	blRad	blWid	blThi
	Original	12	8	7.5	56	15	15	.5
	New	12	8	10	66	15	16	.5
	New thin	12	8	10	66	15	16	.2

Results

The choice of the best blade configuration has been based on the results of several finite element simulations that allowed the evaluation of the tuner strength in different work conditions.

An example of obtained results is pictured in figures 1 and 2, that report respectively the von Mises stresses and the axial load vs. displacement curve for the blade of configuration C. The values reported have been evaluated at the maximum admissible deformation, that has been assumed equal to 70% of blVer (see table 2).

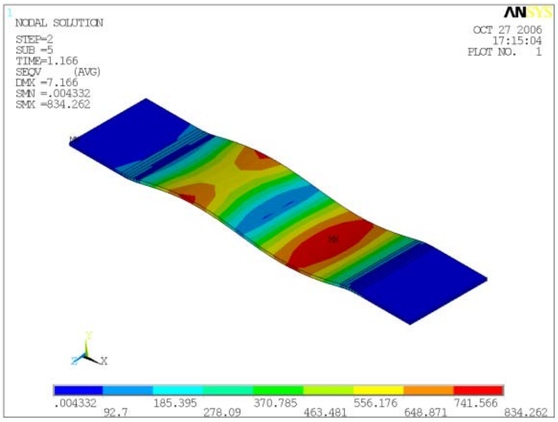


Figure 1: von Mises stresses after the applying of axial load at the maximum admissible deformation of the configuration C blade.

A summary of results is reported in table 3. It contains the loads obtained from limit or buckling analysis, that have been used for the definition of the best blade configuration. A critical comparison of the results point out that:

- configurations B and D are not allowable because of high stresses;
- configuration C has an higher tuning range with respect to the configuration A;
- configuration F can be the optimum solution if the inconel blades can be effectively connected to stainless steel rings by electron beam welding.

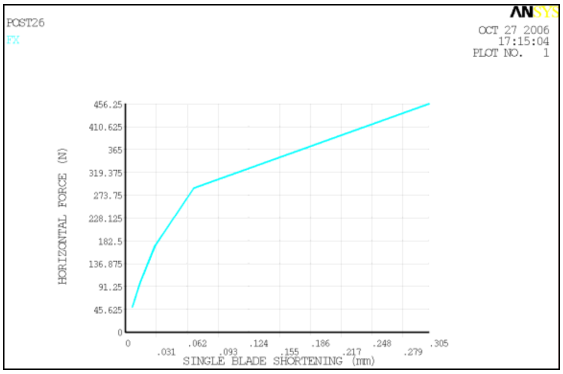


Figure 2: axial load vs. displacement for the configuration C blade at maximum deformation

Table 3: summary of finite element results

Combination	**Limit load in stressed state (N)**	**Max load without plastic strains (N)**	**Limit load in non-stressed state (N)**	**Buckling load in undeformed state (N)**	**Tuning range at cavity (mm)**
A	786	709	669	427	1.1
C	486	456	496	290	1.5
E	46	39	43	31	1.5
F	824	693	804	519	1.5

In order to evaluate the minimum required number of blades, the design force F_S = 4155 N is compared against the buckling value with a safety factor of 3.0 and against the limit load with a safety factor of 1.5. The possible choices are reported in table 4.

Because the final cost will depends from the machining operations, we plan to use a total number of 2x48 blades in configuration C or F. They will be grouped in 6 packs of 4 blades each, for any of the half rings (see figure 3), thus allowing a 75% reduction of welds respects to the original configuration A.

As a consequence of this choice we prefer to use the collinear blade position, and not the alternate one proposed in [6]. This will simplify the machining operations without a noticeable weight increase.

Table 4: minimum blade requirements

Blade conf.	Adm. blade load (N)	Blade stiffness (N/mm)	Minimum number of blade on 360°	
			For strength	For stiffness
A	223	6490	19	8
C	162	5432	26	10
E	14	990	290	51
F	268	10250	16	5

DRIVING SYSTEM SIMPLIFICATION

The existing driving system is composed of a stepping motor that, by means of a leverage arm, moves the two central rings pulling one side and pushing the other one such to have a perfect symmetric system. Unfortunately this solution is cumbersome and expensive. In particular the friction between rotating and translating parts makes them a weak point that has to be solved in a radically way. So that a simplified driving system has been designed, reducing drastically the number and complexity of parts. The new solution is pictured in figure 3 and it is mainly composed of a motor with its harmonic drive and a CuBe screw. The axial movement of the nut is directly transferred in the rotational one by the central rings.

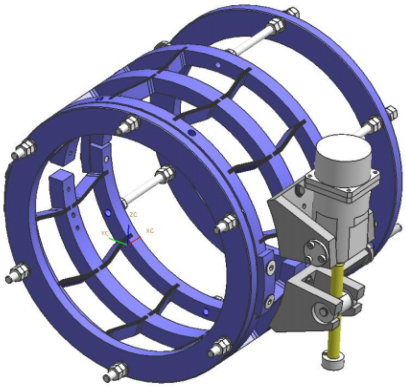


Figure 3: the optimized coaxial tuner for ILC

Although this arrangement simply push away the two central rings, therefore losing the complete symmetry, finite element computations and experimental test proved the effectiveness of the solution. The experimental test was performed in our laboratory by using a simplified mechanism in substitution of the motor (see figure 4). The displacement recorded at the free rings show the perfectly axial movement of them without any rotational or translation effects.

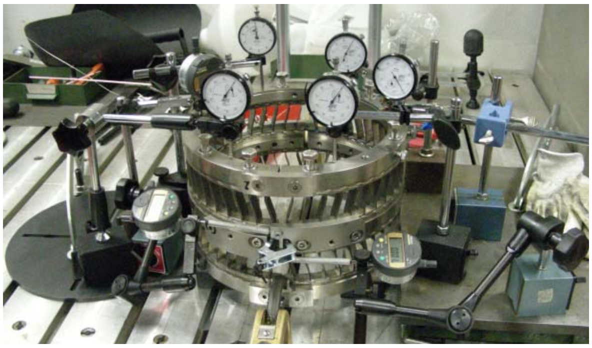


Figure 4: experimental setup to simulate the lateral motor solution.

This result has also been confirmed by finite element computations performed on the new tuner geometry. In particular figure 5 show the axial displacements at the maximum possible deformations of configuration C blades.

The maximum axial force on the motor has been evaluated in 400 N for titanium blades (configuration C) and 800 N for inconel blades (configuration F). These values are fully compatible with the motor and harmonic drive used as of today.

The only apparent drawback of the new design is the increase of the tuning step by a factor of 7. Nevertheless the proposed tuning step of 3 Hz is fully consistent with the experience gained with TTF operation.

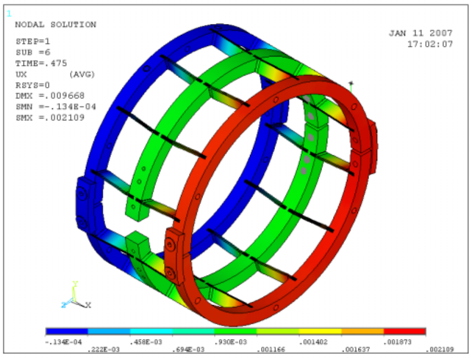


Figure 5: computed axial displacements from FE analysis for blade of configuration C

CONCLUSIONS

The tuner design has been deeply revisited obtaining a much less expensive configuration and the possibility to make it both with titanium and stainless steel rings. This is an important capability in view of future developments.

The new driving system solution is of course the simplest one possible, and it should also improve the overall tuner stiffness.

The estimated cost saving of stainless steel version with respect to the titanium version is of about 1000 €.

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