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Mechanical Simulation with Electrical and Dimensional Tests for AISHa Containment Chamber

F. Noto, G. Costa, L. Celona, F. Chines, G. Ciavola, G. Cuttone, S. Gammino, O. Leonardi, S. Marletta, G. Torrisi

***Abstract*—**At Istituto Nazionale di Fisica Nucleare – Laboratorio Nazionale del Sud (INFN-LNS), a broad experience in the design, construction and commissioning of ECR and microwave ion sources is available. The AISHa ion source has been designed by taking into account the typical requirements of hospital-based facilities, where the minimization of the mean time between failures (MTBF) is a key point together with the maintenance operations, which should be fast and easy. It is intended to be a multipurpose device, operating at 18 GHz, in order to achieve higher plasma densities. It should provide enough versatility for future needs of the hadron therapy, including the ability to run at larger microwave power to produce different species and highly charged ion beams. The source is potentially interesting for any hadron therapy facility using heavy ions. In this paper, we analyzed the dimensional test and electrical test about an innovative solution for the containment chamber that allows us to solve our isolation and structural problems.

***Keywords*—**FEM Analysis, ECR ion source, dielectrical measurement.

I. Introduction

DURING the ‘90s, different ion sources have been built at INFN-LNS, two for the production of highly charged heavy ions to be accelerated by the K-800 Superconducting Cyclotron [1], [2]. All these improvements will be even more remarkable if the proposal of the refurbishment of the 20-years-old cyclotron will be funded: In that case, the demand of high brightness heavy ion beams will further increase of a factor 10 to 100, in order to support the future studies on double beta decay. In the meantime, new projects have been started: The AISHa source for hadron therapy facilities is designed for high brightness multiply charged ion beams with high reliability, easy operations and maintenance. AISHa has been designed to meet the above cited requirements by means of high field He-free superconducting magnets, while the radial confinement will be provided by a Halbach-type permanent magnet hexapole structure. The source will take profit of all the know-how acquired in the years by the INFN-LNS ion source team (Fig. 1). [1]

The new AISHa source is designed to be an intermediate step between the 2nd generation ECRIS (unable to provide the requested current and/or brightness) and the 3rd generation ECRIS [2] (too complex and expensive). At the same time, the electrical power to be installed for its operation will be kept below 50 kW This demand implies also the simplification of all ancillary systems including an oven for metallic ion beams, which permits the production of new beams for hadron therapy and for other applications [3], [4]. The AISHa source (Fig. 1) is funded within the framework of the program of Sicilian Government named PO FESR 2007-2013 and a pool of Sicilian SME is associated with INFN for this project. The source is potentially interesting for any hadron-therapy center using heavy ions.

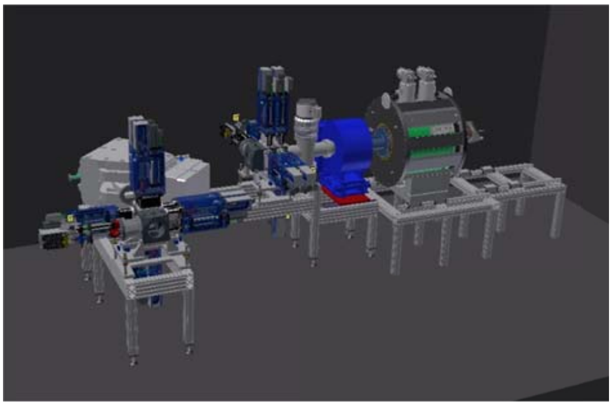

Fig. 1 AISHa layout

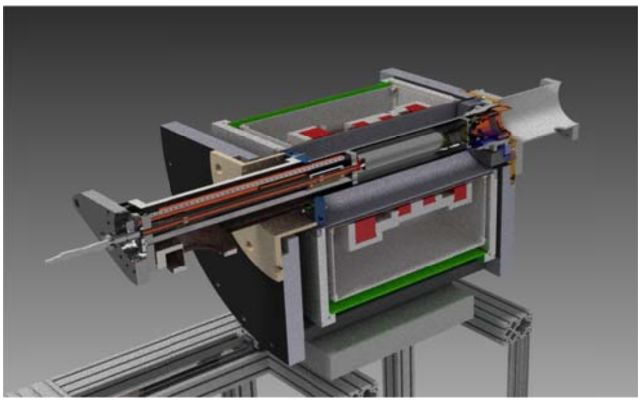

Fig. 2 ¼ AISHa Section layout

II. Simulation

A. Mechanical Development

In order to minimize the maintenance operations, the development of new source involved some mechanical and structural improvements with respect to similar devices. In particular, hereinafter the optimization of the hexapole

F. Noto is with the Istituto Nazionale Fisica Nucleare – Laboratori Nazionali del Sud, Catania, 95123 Italy (corresponding author to provide phone: +39 095 542802; e-mail: giuseppe.costa@lns.infn.it.

G. Costa, L. Celona, F. Chines, G. Cuttone, S. Gammino, O. Leonardi, S. Marletta, G. Torrisi are with the Istituto Nazionale Fisica Nucleare – Laboratori Nazionali del Sud, Catania, 95123 Italy

G. Ciavola. is with the CNAO Foundation, Strada Campeggi, 53, Pavia PV, Italia.

containment chamber.

B. Use of COMSOL Multiphysics

The Finite Element Method approximates a Partial Differential Equations problem with a discretization of the original problem based on a mesh, which is a partition of the geometry into small units of simple shape called mesh elements [3]. The PDE method looks for a solution in the form of a piecewise polynomial function, each mesh element defining the domain for one "piece" of it. Such a piecewise polynomial function will be expressed as a linear combination of a finite set of predefined basis functions. Let us consider for example a 2-dimensional problem with a single dependent variable *p(x,y)*. We would like to solve this problem based on a mesh with quadratic triangular elements [5]. The expression "quadratic elements" refers to the fact that on each mesh element the sought piecewise polynomial function $p*(x,y)$ is at most a quadratic polynomial [6]. In this case, the solution is expressed as:

$$p(x,y) \cong p*(x) = \sum_i^n p_i\, i * \varphi_i(x,y) \quad (1)$$

where *i* refers to a node of the mesh, pi are the degrees of freedom, $\varphi_i(x,y)$ are the basis functions and n is the total number of nodes, under the assumption that each triangle of the mesh possesses six nodes: three corner nodes and three mid-side nodes [7]. A basis function $\varphi_i(x,y)$ has here the restriction to be a polynomial of degree at most 2 such that its value is 1 at node *i* and 0 at all other nodes [8]. The degree of freedom pi is thus the value of $p*(x,y)$ at node *i*. The definition of the basis function associated to each node of the mesh can be derived using for example a general method introduced by Silvester in 1969 [9].

C.Simulation Cylinders of the Containment Chamber Made of Composite Material

The goal of our study was to study deformation and stress on the assembly. Our assembly (Fig. 2) is composed of two parts: Glass Fiber (grey) and Carbon fiber tube (blue).

We used Solid Mechanics module for our simulation: we assumed some of the domains as free (blue) (Fig. 3). We assumed some of the domains as fixed (blue) (Fig. 4).

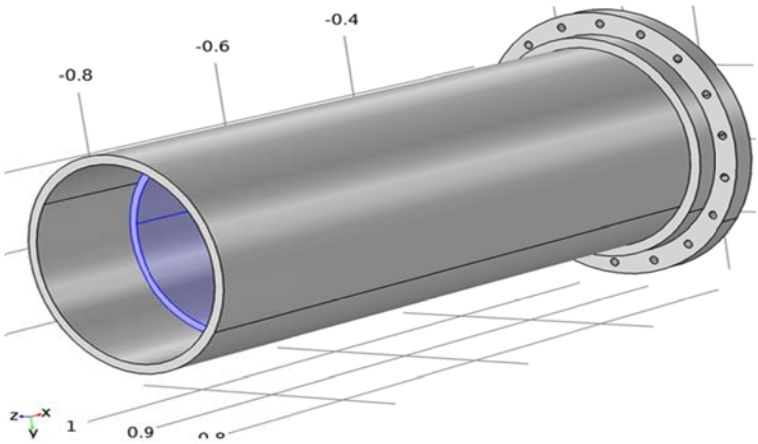

Fig. 2 Geometry of the simulation

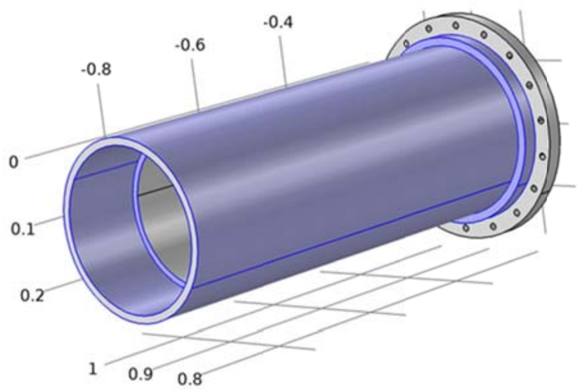

Fig. 3 Free domains

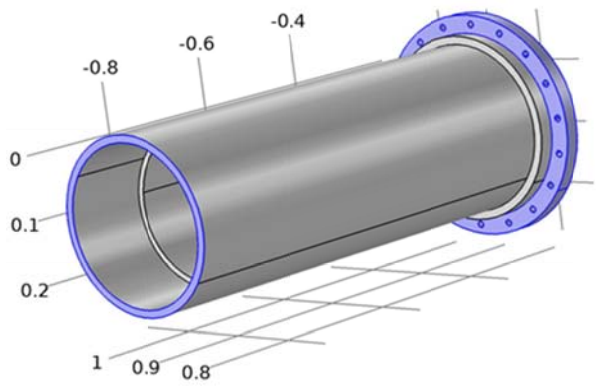

Fig. 4 Fixed domains

We considered a pressure of 1,05 * 10^6 MPa applied in the internal surface (blue) (Fig. 5). We used a dense mesh for all domains (Fig. 6). The simulation gave us these results: A maximum value of deformation of 0,3 mm and a maximum value of stress of 8 MPa (Fig. 7).

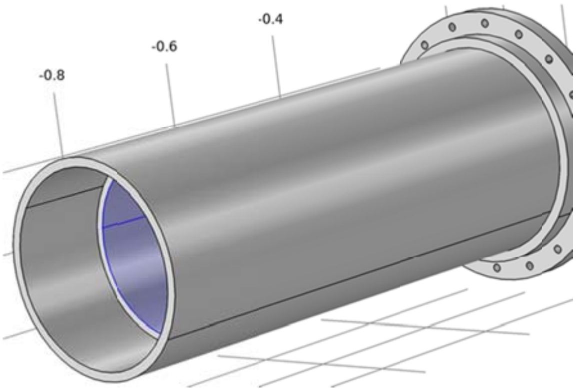

Fig. 5 Load applied

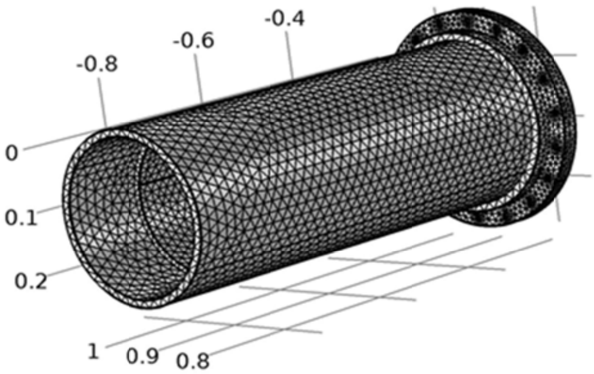

Fig. 6 Mesh of the model

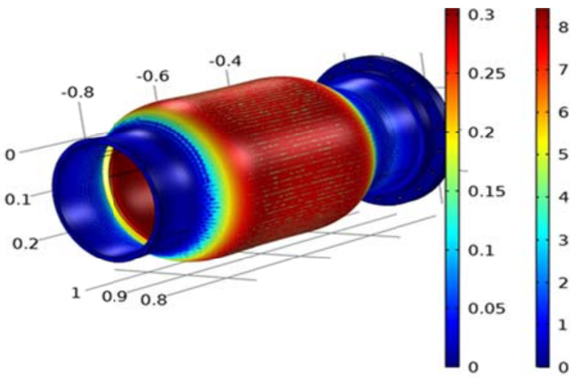

Fig. 7 Results of the simulation

III. Dimensional Checks

The dimensional inspection of models and molds has an important implication from economical the point of view as it avoids starting the production of manufactured goods that do not comply technical specifications and which would lead to the deviation of the final product, resulting in a waste of human and material resources. In the analysis they had frequent problems reflection of the beam due to the high reflectance of the surfaces scanned. The dimensional inspections of the built workpieces are done only in special cases because they were usually unnecessary; the dimensional inconsistencies can be transferred from the mold to the piece, rarely these arise in the lamination step of the mold. Through to these measures, the incidence of dimensional errors on the finished product is negligible, and during the test at company there were no such cases.

A. Testing Company

The measurement campaign radial was made, one for each different position under investigation and all the measures had the precision of a tenth of a millimeter. The measurement campaign has been satisfactory. After the company testing we shipped the containment chamber at new company to install the tube in the yoke; this operation was successful (Fig. 9).

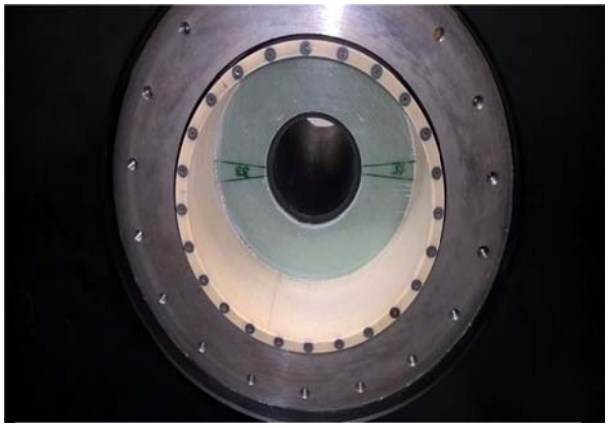

Fig. 8 Containment tube in yoke tube

B. Dielectrical Test

The test of dielectric strength fixes the ability of withstanding by an overvoltage without producing a field discharge. This overvoltage can be caused by lightning or generated by a fault on the transmission line energy. The main objective of this test is to verify that the procedures for building materials and insulation distances have been respected. The test is often performed by applying an alternating voltage, but it is also possible to use a DC voltage. The device suitable for this type of measurement is the di-electrometer. The result is a voltage value expressed in kV, and presents a more or less destructive levels of testing (quality tests or maintenance). For this reason, the dielectric test is run on new equipment or regenerated. The measurement of the insulation resistance is not considered destructive under normal test conditions. It is performed applying a DC voltage, lower than the dielectric test, getting a result expressed in Resistance (kΩ, MΩ, GΩ, TΩ). This resistance value expresses the quality of insulation between two conductive elements; its non-destructive nature makes it particularly suited for the control of ageing of the insulators during the normal period of operation of an apparatus or of an electrical installation. This measurement is performed by a controller insulation also called megohmmeter.

C. Test Pieces of Dielectric Strength

The set of the electrical equipment (Fig. 8) must comply with the insulation characteristics to ensure their operation in maximum safety; in particular, the containment tube, made of composite material, must be able to withstand a total of 40 kV.

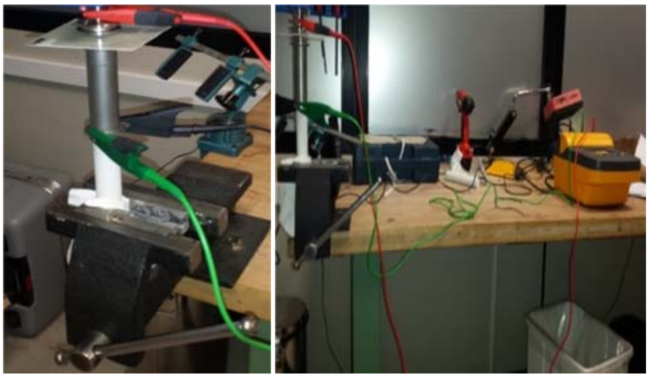

Fig. 9 Measurement analysis

D.Principle of Measurement of Insulation and Factors Affecting It

The measurement of the insulation resistance is based on Ohm's law. By applying a DC voltage of known value and lower than that of the dielectric test, it measures the current and determines the resistance value. At the beginning the insulation resistance presents a very high value but not infinite and then, with the measure of the weak current flowing, the megohmmeter indicates the value of the insulation resistance with a result in kΩ, MΩ, GΩ, or for some models, in TΩ. This resistance value expresses the quality of the insulation between two conductor elements and provides a good indication of the possible risks of circulation of leakage currents. When a constant voltage is applied to the circuit tested, the measurement of resistance and the value of current are affected by some factors as the temperature or humidity that could produce a change of the measure.

IV.Conclusion

In this paper we study a new technical solution for a ECR containment chamber. We are simulated a glass fibers and carbon fibers tube with a FEM software and the results showed the compatibility and the strength of these materials. The electrical point of view is also very important and this technique is very interesting.

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References

[1] F. Noto et al., Structural Optimization of the AISHa Ion Source – ISBN: 978-0-9910001-8-0 ISSN: 2372-2215
[2] S. Gammino et al., Rev. Sci. Instrum. 70,9 (1999), 3577
[3] S. Gammino, G. Ciavola, Rev. Sci. Instrum. 71, 2 (2000), 631
[4] F. Noto et al. - Structural Mechanics Optimization of the AISHa Ion Source - Proceedings of the International Conference on Computational Methods (Vol.2, 2015) ISSN 2374-3948
[5] L. Celona, et al. - A Compact Multiply Charged Ion Source for Hadron Therapy Facility - Proceedings of IPAC2015, Richmond, VA, USA WEPWA031
[6] F. Noto et al, Optimization of the Gas Flow in a GEM Chamber and Development of the GEM Foil Stretcher. Nuclear Technology & Radiation Protection (2014) ISSN: 1451-3994 - DOI: 10.2298/NTRP140SS39N
[7] Felippa C.A., Introduction to Finite Element Methods, lecture notes, Department of aerospace engineering sciences of the University of Colorado, Boulder, 2004.
[8] COMSOL Multiphysics User's Guide v4.1, COMSOL A B, 2010.
[9] Lewis R.W., Nithiarasu P. & Seetharamu K.N., Fundamentals of the Finite Element Method for Heat and Fluid Flow, New York, John Wiley & Sons, 2004.

Francesco Noto, 21/07/1975; Master degree in Mechanical Engineering, Catania's University, Italy.

In 2003, he started to work at the INFN – Catania's Section, as a fellow to the CMS experiment at CERN in Geneva. For this experiment has served as a mechanical designer and subsequently responsible for the mechanical testing experiment called "Cosmic Magnet Test Challenge" at CERN. In 2007 moved to Alice experiment, with a check for technological research at the University of Catania, serving as head of the mechanical integration EMCAL detector at CERN. In 2009 he began to collaborate with the experiment JLAB12 with the role of mechanical mananger for the GEM particles tracker. From 2012 he collaborated with the experiment ICARUS and later with the WA104 experiment to CERN in Geneva, where he served as a mechanical designer with a PJAS contract at CERN. From 2014 he was as mechanical mananger design for the experiment AISHA at the LNS. From 2010, he served as an adjunct professor for the Catania's University, teaching physics and materials science. He collaborated with the ICCM conference which is a member of the Scientific Committee.

Author of numerous publications including:

- F. Noto et al - Structural Mechanics Optimization of the AISHa Ion Source - Proceedings of the International Conference on Computational Methods (Vol.2, 2015) ISSN 2374-3948.
- F. Noto et al, Optimization of The Gas Flow in A GEM Chamber And Development Of The GEM Foil Stretcher. Nuclear Technology & Radiation Protection (2014) ISSN: 1451-3994 - DOI: 10.2298/NTRP140SS39N
- F. Noto et al - Development of membrane cryostats for large liquid argon neutrino detectors, Proceedings CEC-ICMC 2015-C1PoJ-01, Contribution ID: 303
- CMS Collaboration, Including, Noto F. (2012). Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC. Physics Letters. Section B, vol. 716; p. 30-61, ISSN: 0370-2693, doi: 10.1016/j.physletb.2012.08.021