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Design and Development of High Current Pulse Shaping Inductor Based on Bitter Magnet Configuration for Electro Magnetic Launcher

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Abstract*: A unique pulse shaping inductor was designed and developed using a modified Bitter magnet configuration, to operate at peak current of 150 kA for duration of 5-10 ms in a Pulse Forming Network (PFN). The inductor was designed with a stack of parallel copper plates in the form of circular discs with a central hole, with GRP insulation plates in between. The design is optimized by electromagnetic finite element techniques for inductance and structural stability. The conducting discs and insulators are clamped together with tie rods between two endplates to provide adequate contact pressure and sufficient mechanical support. The conducting, inter connecting and insulating components were modeled and optimised parametrically for the desired performance and structural integrity. The device was fabricated, assembled and tested with 24 bitter plates for 28 µH inductance. The inductor was integrated with 400 kJ capacitor bank module and tested under static and dynamic condition. Current pulse of peak above 100 kA was generated, with consistent arc-free performance, high reliability and structural stability.

Keywords* : Bitter Coil, Pulse Inductor, Electromagnetic launch, Railgun, Pulsed Power.

I. INTRODUCTION

Enhancement of projectile velocity of a gun has the advantage of higher range, better lethality, accuracy and better penetration capability. The plateauing performance of the conventional artillery gun is related to the fact that the projectile velocity is closely related to the velocity of accelerating gases, which primarily depends on the velocity of sound in the gases. Thus it is seen that the conventional guns reach a peak velocity of around 1600 -1800 m/s. Adding more charge results in entering a regime of diminishing returns with most of the work wasted in accelerating the additional charge [1]. Many ways to overcome this velocity limit were explored, including light gas guns, heavy guns, and guns with excessive propellants [2-5], wherein the Electromagnetic gun- railgun- with a totally different propulsion technology has emerged as the practical and feasible solution to launch hypervelocity projectile.

Railgun is purely working on electrical pulse-power and no accelerating gas is involved. It uses electromagnetic field pressure ($J \times B$ forces or Lorentz force) created by current flow in a pair of parallel rails to accelerate projectile- which is in sliding contact between the two[6,7]. Keeping this in view, development of Electromagnetic Launcher was initiated across the globe, some of them in research point of view, some on launching micro satellite and some on military applications [8-11].

Various power sources including flywheel based Compulsators, Inductive storage and battery banks were experimented as the power sources for railgun [12-15]. However Capacitor Banks turned out to be the most reliable, easy to use solution. But as the energy density of storage capacitors are less, the system tends to be bulky[16,17]. A preliminary work on the development of Electro magnetic launcher was taken up with an aim to establish the technology powered by capacitor bank.

A pulsed power system based on Capacitor bank was designed and developed to power the Railgun. The capacitor bank is assembled with modular configuration with module of 400 kJ of capacitors; some modules having eight 50 kJ capacitors and others having four 100 kJ capacitor. The capacitors are connected parallel, charged to the desired charging voltage and switched simultaneously to the load through a high current switch.

The modules are integrated with Ignitrons as main switch and crowbar and a pulse shaping inductor. The pulse shaping inductor is essential to have the pulse duration to be limited to the time of propulsion of the projectile within the railgun [19].

II. CAPACITOR BANK MODULE

When a capacitor bank based power source is used to power a railgun, it is necessary to limit the peak of the current and extend the pulse to a longer duration. This is because railgun in itself has a very low impedance (more so at starting when armature acts as a dead short) and as such the current will reach to very high values and the pulse duration will be very short - not enough to accelerate the projectile through the complete barrel, which is, typically, 2 m to 10 m in length. In order to limit the current an inductor is used in series with the capacitor as shown in the circuit (fig 1).

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The inductor limits the peak current of the discharge when the capacitor is switched into the railgun and also elongates the pulse.

A schematic configuration of the capacitor bank module is as shown in Fig 1. At time t=0, the main switch is turned on, the circuit behaves as a first order LC circuit, and current starts to rise from zero, limited by the inductor. When the current reaches the peak, the voltage at the capacitor is approximately zero. At this point the complete energy of the capacitor has been transferred to the inductor and the load (railgun), and the capacitor is no longer needed in the circuit. A further continuation in this state would charge the capacitor in reverse direction and further oscillations will occur. In order to prevent this, a crowbar switch gets turned on and cuts off the capacitor from the main circuit. The inductor which has now the majority of the energy initially stored in the capacitors continues to feed the railgun for further operation.

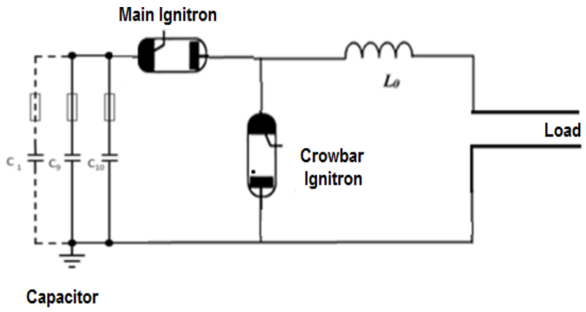


Fig 1. Schematic configuration of Capacitor Bank module. Energy storage capacitors are connected parallel. Ignitrons are used to switch the capacitor energy to the load (railgun) as well as used as crowbar switches

The capacitor bank circuit was simulated using Microcap software for simultaneous and sequential firing of capacitor bank modules [18]. With various iterations, the module peak current requirement was optimized at 150 kA peak with varying pulse shapes in case of sequential firing. This further demands the requirement of pulse shaping inductors of 10 to 30 µH with every module of capacitor bank. In case of pulsed power systems, the inductor design is crucial as large pulsed current high peak value create huge magnetic field which in turn exert large force on the inductor structure. The inductor elements - which are current carrying, insulating and supporting- have to be mechanically reinforced to withstand these large forces.

III. BITTER COIL CONFIGURATION

The pulse shaping inductor required to be operated at peak current up to 150 kA at a voltage of 11 KV. A coil carrying such current experiences huge compressive force along the axial direction and heavy repulsive force in the radial direction. Different inductor configurations are used for various railgun systems, including special solenoids and Jelly Roll inductors [20]. Considering the drawbacks of solenoids at high current and high forces and the difficulty of fabrication of Jelly Roll structure, configuration of bitter magnet was considered as a practical solution [21]. Bitter magnet is the high-power magnet invented by Francis Bitter in 1936. It is constructed of perforated, round, wide conductor plates, the *"Bitter disks"*, interleaved with insulators, and which are stacked to form a thick monolayer winding [22-23].

Zaitov and Kolchuzhin has given a complete theoretical, design and manufacturing aspects of Bitter Coil for metal processing [24]. The design was catered for the critical current density distribution which is inversely proportional to its radius. Various aspects on material selection, design parameters, design limitations were taken in to account in the instant design and development. However a different approach is used to develop the inductor for capacitor bank, mainly a parametric approach - using finite element methods for parametric optimisation. Normally the bitter coil plates are with circular geometry. However, rectangular plates are also used to develop successful performance of bitter magnets [25].

The coil under development was designed with circular disks made from sheet metal of copper or copper alloys. The structure is found to be simple in construction. The Bitter discs used are of considerably broad size with large surface area. This results in the reduction of stress concentration, preventing structural failure. It is having other advantage of adjusting the inductance by varying the number of bitter plates. The assembly involves only nut-bolt arrangement and hence the process of assembling and dis- assembling is easy. Also it does not involve sophisticated machining or winding/ twisting of thick metallic blocks.

Bitter discs are to be separated by suitable insulator. As the parallel discs are carrying currents of peak value of 150 kA in the same direction, the insulator plates introduced between them experience tremendous compressive force. Insulator material is suitably selected so as to survive such compressive stress. Along with that it should be ensured that it should sustain disc-to disc potential difference, without leading to voltage breakdown.

IV. PULSE SHAPE INDUCTOR DESIGN

A simplified analytical expression for the inductance of Bitter coil is provided by Dylan O. Sabulsky et al.

$$L = \frac{\mu_0 N^2}{4\pi} a_1 \Lambda\left(\frac{a_2}{a_1}, \frac{t}{a_1}\right) \text{-----} (1)$$

Where, *N*- Number of turns. a_1 – Inner Radius, a_2 – Outer Radius, Λ- Factor of self inductance and *t*- Half height of the Electro Magnet . The dimensionless factor of self-inductance depends only on the current distribution and geometry of the electromagnet [26].

ETP copper plates of 3 mm thickness were considered for Bitter plates and interleaving plates with 3 mm Glass reinforced Plastic (GRP) sheets for insulator in between the bitter plates. Copper plates of 6 mm thickness are considered at top and bottom. Clamping of the plates was done by steel plates with higher radius placed on top and bottom. An initial model of the bitter coil is as shown in Fig 2. Overall configuration and current flow is indicated in Fig 3.

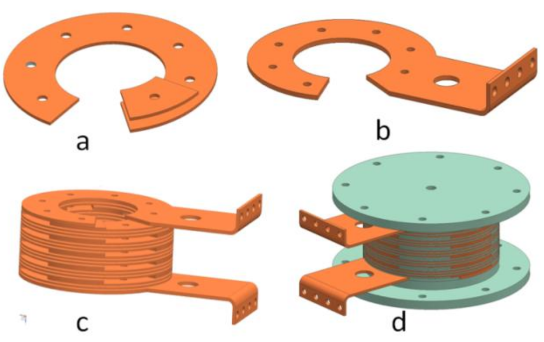


Fig.2 Bitter coil components and assembly: a. Bitter plate and inter-leaving plate, b. Top and bottom plates (Connecting Plates) c. bitter plate assembly (conducting plates) d. complete assembly.

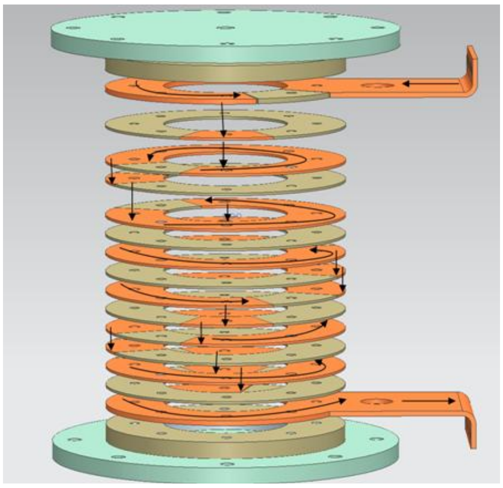


Fig 3. Bitter coil configuration with the current flow directions in the components

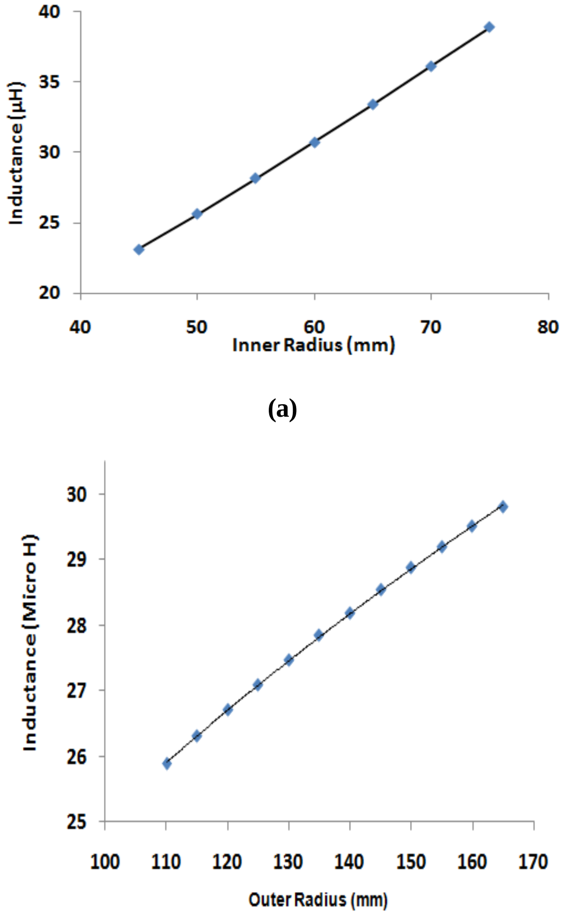
V. PARAMETRIC OPTIMIZATION OF INDUCTANCE

For the initial design of the bitter coil, bitter plate thickness is fixed as 3mm, due to availability of copper plates. Various values of inner and outer radius was numerically derived using eq.1, assuming reported values self-inductance factor. Bitter coil model was generated in Maxwell EM software with such derived approximate values and number of plate. The model was analysed under 'optometric' for outer radius, inner radius and number of plates for the inductance variation. . Number of iterations are carried out fixing one parameter and optimising other. Even though Eq.1 indicates that the Inductance increases with the square of the number of plates, it in turn contributes to the height of electro magnet as well. Hence the variation of inductance with the number of plates also was studied using Maxwell (Fig 5). After various iterations, as represented in Fig 4 and Fig 5, the optimum parameters for 28 micro Henry were obtained with inner diameter of 110 mm, outer diameter of 280 mm with 24 bitter plates.

VI. ELECTROMAGNETIC ANALYSIS

A. Static analysis using EM-FEM

Bitter coil need to function at extremely high peak currents, of the order of 150 kA. The system is required to be used on the Pulsed power module of EM Launcher. Hence there is a need to simulate the condition and establish the electrical and structural integrity at actual conditions. A parametric software using the EM-FEM (Electro Magnetic Finite Element Method) was developed to evaluate various electrical and structural element [27]. Complete electro-magnetic analysis of the design was carried out to evaluate the current density distribution and magnetic field distribution using Electromagnetic FEM (Fig 6).



(a)

(B)

Fig.4. Bitter Coil Optimisation studies: Inductance variation of 24 plates bitter coil with a. inner radius with OD of 290mm and b. outer radius with ID of 150 mm

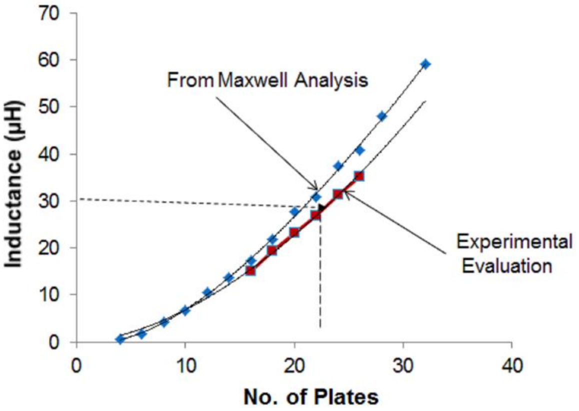


Fig.5 Variation of Inductance with number of plates.

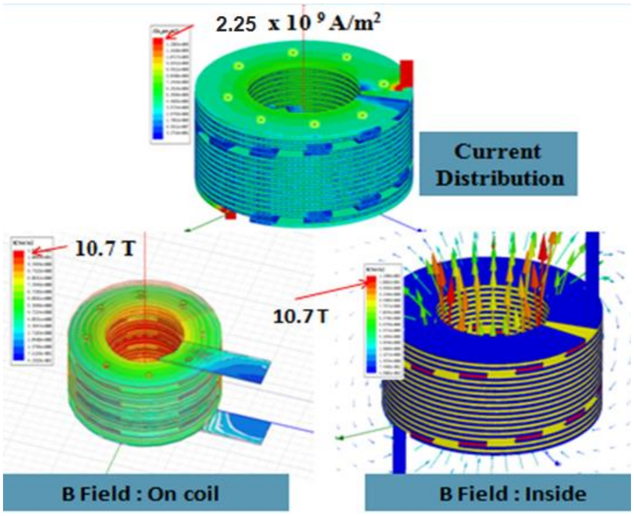


Fig.6 Bitter Coil current & field distribution analysis using static analysis. 150 kA Pulsed current is considered for analysis

The designed Bitter coil has current density concentration towards the inner edge with maximum current densities of the order of 2.25 kA. /mm^2. Also generate magnetic flux density up to 10.7 Tesla.

Static analysis helped to have a preliminary design of the bitter coil. Even though the software is easy to use and fast in operation, it suffers from the disadvantaged that the current input to be fed as a constant pulse with the desired pulse width, Variation of the instant current value over the pulse duration is not considered.

B. EM Analysis with Commercial Software

The EM analysis has been carried out in commercially off the shelf available ANSYS MAXWELL Software which is also working on EM-FEM. The analysis used the pre-defined current pulse generated out of micro cap simulation of the module, as the input given to the end plate of the bitter coil. The force distribution generated by MAXWELL is directly fed to ANSYS STRUCTURAL for structural analysis on the workbench.

MAXWELL provides flexibility to carry out both magneto static and transient analysis. To carry out the B-field distribution and current distribution, transient analysis has been carried out. The input for the analysis is considered as a current pulse of peak 150 kA with a duration of 2 ms as shown in Fig. 7. The current pulse was generated out of the circuit analysis of the actual pulse module circuit to be used in the launcher, with a scaling factor to take care of safety aspects. The circuit analysis was carried out using Microcap. The current density distribution along the face and the radial current distribution are shown in Fig 8.

The peak current density 3 x 10^9 A/m^2 was observed at the inner circumference of the plate. The concentration of the current at the core side of the coil can be clearly seen. This is visible from the current distribution on one bitter plate is shown in Fig 9.

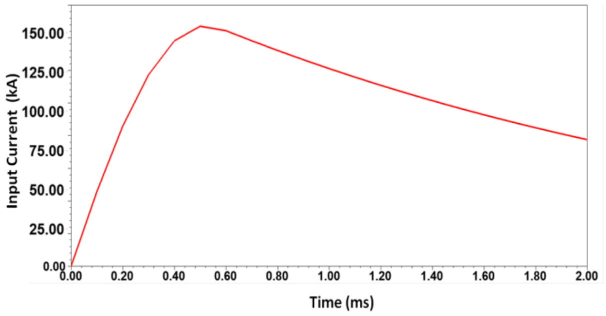
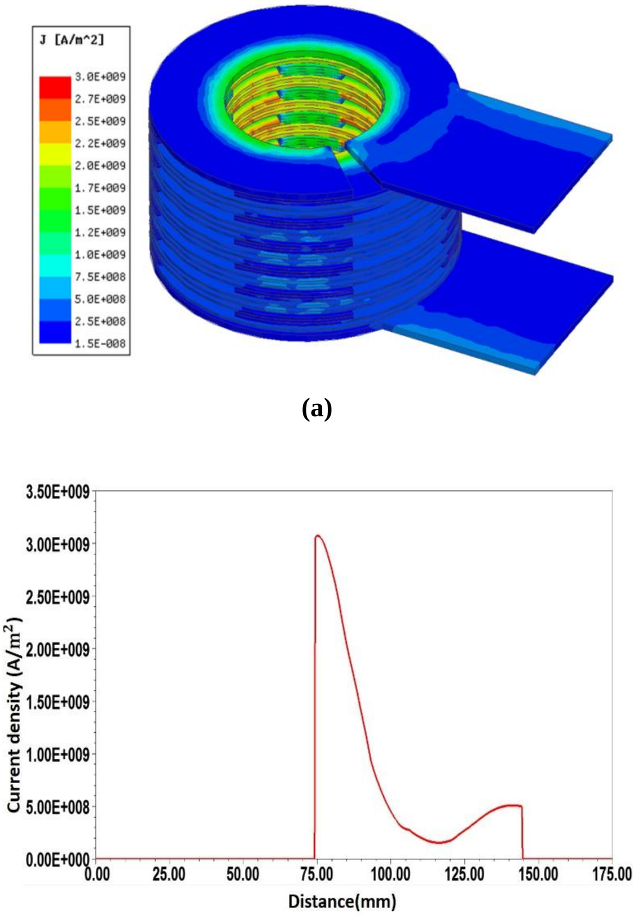


Fig.7 Current pulse profile used as the input for Bitter Coil simulation



(a)

(b)

Fig.8 Current Distribution: a- Radial Current Distribution on the bitter coil, b-Variation of Current density from center to periphery (Origin is taken at 15 mm from the inner edge of the plate towards the centre)

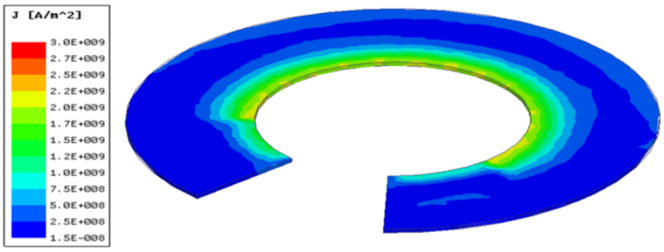


Fig.9 Current Distribution on a bitter plate

The disadvantage of such current distribution is also evident that the current cross section becomes smaller and hence the ohmic losses and the local heating of the coil become higher. The effectiveness of bitter coil is on the current distribution over the entire plate surface, reducing force and stress concentration, but the simulations indicated that that will not happen very effectively at the desired operating levels.

The B-field distribution is shown on Fig 10. The current concentrates at the core of the coil. So the magnetic flux present in the core region of the coil is hindered by the skin effect and fails to expand radially into the conducting material. This increases its field density at the inner edge of the Bitter plates. The shorter the pulse the higher the B-field will be. This "compressing effect" of magnetic field is demonstrated in the Fig. 11, showing the radial distribution of the *B field* over a plate. The inner side of the conductor just at the core has higher B-field.

The axial B-field at the core of the bitter coil indicates that the field is concentrated at the centre of the coil, like any other inductor (Fig 12).

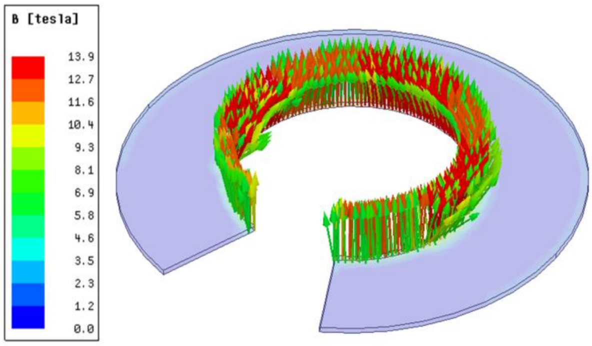


Fig.10 B-field Distribution in a bitter plate

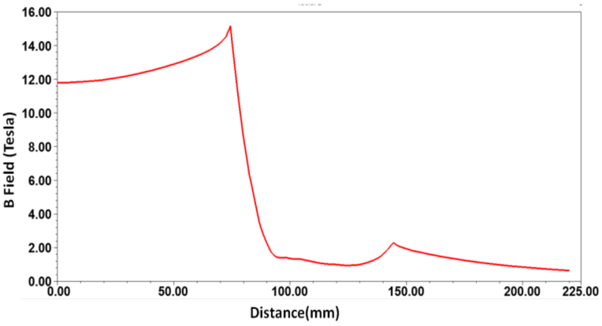


Fig.11 Radial B-field in a Bitter coil under transient evaluation. X axis origin is at the centre of the disc. Magnetic field increases from the centre to the inner edge and concentrate at the inner edge of the bitter disc,

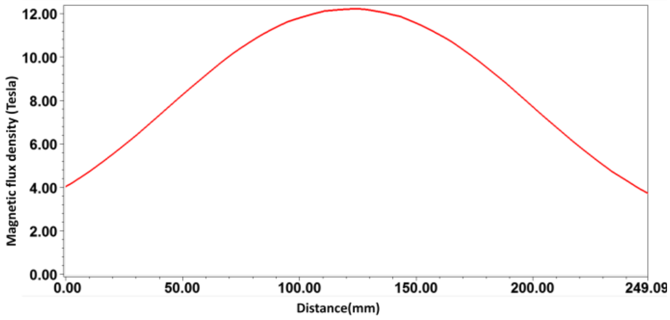


Fig.12 Axial B-field in a Bitter coil

VII. STRUCTURAL ANALYSIS

An Electro Magnetic solver was developed for the static EM and structural analysis software using finite element methods in electromagnetics (EM FEM) [28]. The force distribution is evaluated by the CEM solver. This is further fed to ANSYS for structural analysis. The von Mises stress distribution at 150 kA peak pulse current is as in Fig 13. It was observed that the maximum stress level on the conducting plate is 220 MPa, which is localised. On the insulator side the maximum stress is less than 120 MPa.

The Bitter coil was fabricated using 3 mm ETP copper sheets (Compressive strength of 260 MPa) as conducting sheets and GRP sheets (beyond 350 MPa) as insulator. On the top and bottom, 6mm copper plates are used for increased strength. GRP plates of 20 mm thickness were used above and below the assembly for insulation and confinement. Further 20 mm thick SS plates (420 mm Diameter) are kept on top and bottom for applying prestress.

Pre-stress was applied using 08 numbers of tightening bolts between the SS sheets with bolt placed (M12 bolts) at the periphery with a PCD of 350 mm and one thicker bolt (M24) at the centre. Bolts are isolated using insulation wrapping.

VIII. INTEGRATION AND TESTING

The bitter plates, interleaving plates and insulator plates were fabricated and the coil was assembled. During assembly, special care was taken that the current flow through the entire coil is uni-directional. 24 Bitter plates are assembled to form the final assembly. The DC resistance of the assembly was 2.76 mΩ and the inductance value was found to be 31 µH in place of designed 28 µH. The module current was re-simulated with the observed value of Inductance. The insulation test with the body and the conductor part was carried out up to 15 kV and found to have good insulation resistance (> 50 GΩ).

Frequency dependence of bitter coil performance was evaluated. Variation of coil resistance and inductance was measured at various frequencies.

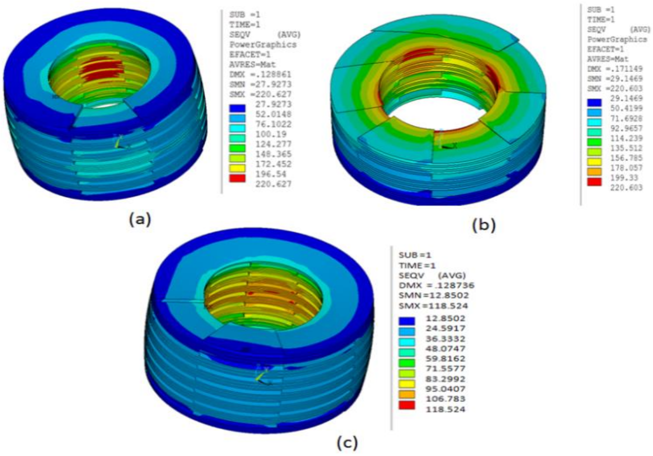


Fig.13 Stress analysis of Bitter Coil Components on application of pulse current of 150 kA peak – von Mises stress levels a. On Bitter plate assembly, b. on the centre bitter plate and c. on Insulator plates

As the pulse generated peak at around 500- 600 microseconds, an equivalent frequency of 400 Hz was considered for the pulse operation of the capacitor bank system. Accordingly, operational values of inductance and resistance are taken as 22 µH and 8mΩ respectively. The variation of resistance and inductance with frequency is shown in Fig. 14.

Multiple bitter coils were assembled with the same design and it was observed that all have consistent inductance and resistance at DC condition. The inductor is assembled with 400 kJ capacitor bank module along with an NL 488 ignitron main switch and NL496 ignitron as the crowbar switch. Specific connector assembly was designed and fabricated to connect the bitter coil output to the high current co-axial cable. The output is connected with a low resistance load (2mΩ) similar to railgun resistive load. Capacitor bank module is charged to various voltage levels and discharged to the load using Ignitron switches, through the bitter coil. The current pulse across the load was recorded using current transformer. The peak current and current profile were closely matching with the simulated results, indicated that the bitter coil thus developed is meeting the design requirements (Fig 15).

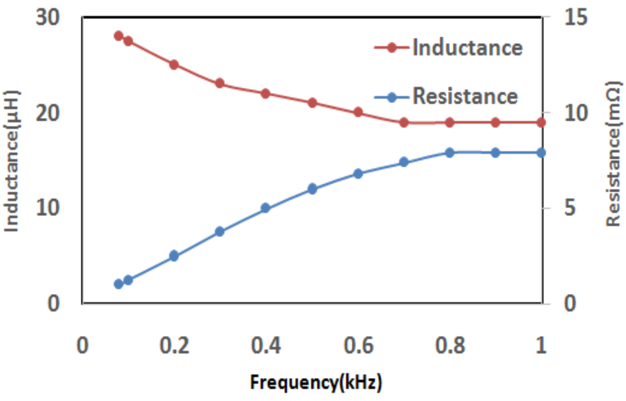


Fig.14. Variation of Inductance and resistance of the Bitter coil with frequency (Experimental)

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Fig.12 Bitter Coil of 24 µH at 400 Hz. This has 8 mΩ DC resistance and weight of 68 kg

IX. EDDY CURRENT ISSUES

It was observed that the clamping nuts are getting loosened after multiple high current pulse operation. This was clearly observed at peak currents above 100 kA. Loosening of the bolts resulted in the loss of contact between bitter plate and interleaved plate resulting in to arcing. This demand the tightening of all bittercoil bolts after every operation of high current.This phenomenon was initially thought of momentary compression of plates as the current pulse reaches peak value and immediate relaxation as the pulse reaches zero. Along with this, the effect of eddy current at the top and bottom clamping plate was studied. Further analysis of the metallic plate in Maxwell indicated the formation of tremendous eddy current over the clamp plates. The induced current generated current densities above 100 MA/m^2 (Fig 15). Subsequently these plates were replaced with GRP plates. The coils were found to be much stable and devoid of arcing issues.

X. CONCLUSION

A pulse shaping inductor is an essential components for the EM launcher, which controls the electrical pulse generated for the application by ensuring proper pulse shape. The device was successfully designed, developed and tested based on the Bitter coil geometry. It offers lot of flexibility and adaptability. Multiple bitter coils were fabricated, assembled and tested at various voltages and load levels and were showing consistent results. Even though the initial assembly lead to arcing issues and issue of un-balanced forces, proper evaluation of the problem, analyses and implementation of corrective methods helped to establish consistent arc-free performance of this critical component.

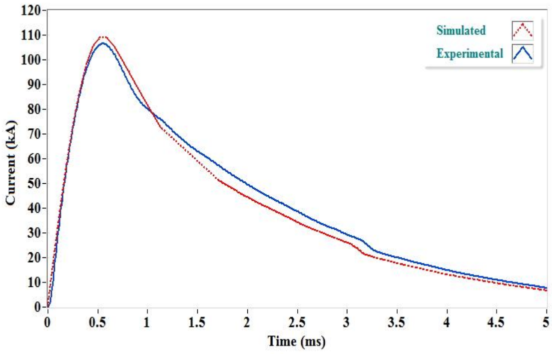

Fig 15. Current Pulse from 400 kJ Capacitor Bank Module at 8 kV Discharge

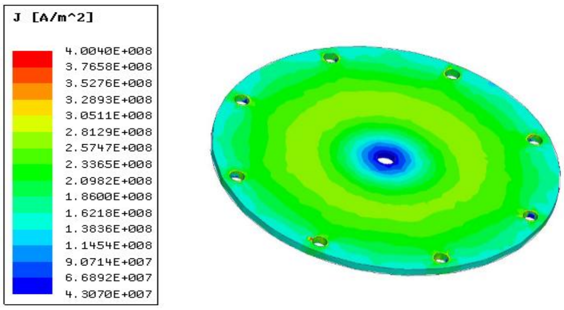

Fig.16. Eddy current induced in the clamping steel plate

REFERENCES

1. Marshall RA, Railgunnery: "Where have we been? Where are we going?", *IEEE Trans. Magnetics*, 37(1), Jan 2001, pp 440-444.
2. L C Chhabildas, L.N.Kmetyk, W.D.Reinhart and C.A.Hall, "Enhanced hypervelocity launcher - capabilities to 16 km/s"; *International J. of Impact Engineering*, 17(1-3), 1995, pp 183-194.
3. A.J.Piekutowski. K.L.Poormon; "Development of a three-stage, light-gas gun at the University of Dayton Research Institute", *International J. of Impact Engineering*, 33 (1-12), 2006, pp 615-624.
4. T. J. Ringrosea et al.; "A hypervelocity impact facility optimised for the dynamic study of high pressure shock compression", *Procedia Engineering* 204, 2017, pp 344 –351.
5. DA Tidman, DW Massey; "Electrothermal light gas gun", *IEEE Trans. Magnetics*, 29, 1993, pp 621-624.
6. Henry Kolm, Peter Mongeau and Fred Williams; "Electromagnetic Launchers", IEEE Trans. Magnetics; 16, 1980, pp 719-723.
7. McNab I.R., "Pulsed power for electric guns," *IEEE Trans. Magnetics*, 33(1), 1997,pp 453-460.
8. M. Schneider, M. Woetzel, and W. Wenning, "The ISL Rapid Fire Railgun Project RAFIRAPart I: Technical Aspects and Design Considerations", *IEEE Trans. Magnetics*, 45(1), Jan 2009, pp 442-447.
9. U. Hasirci et al.; "Concerning the design of a novel Electromagnetic launcher for earth-to-orbit micro- and nano satellite systems", *IEEE Trans. Plasma Science*, 39(1), Jan 2011, pp 498-503.
10. Zielinski AE and M Werst, "Cannon –Caliber Electromagnetic Launcher", *IEEE Trans. Magnetics*, 33(1), 1997, pp 630 – 635.
11. I. R. McNab, Fellow, IEEE, and F. C. Beach; "Naval Railguns", *IEEE Trans. Magnetics*, 43 (1), 2007, pp 463-468.
12. Gully J.H., "Power supply technology for electric guns", *IEEE Trans. Magnetics*, 27(1), 1991, pp 329-333.
13. W.A Walls et al., "A field based, self-excited compulsator power supply for a 9 MJ railgun demonstrator", *IEEE Trans. Magnetics*, 27 (1), 1991, pp 335-340.
14. S. B. Pratap et al., "A compulsator driven rapid-fire EM gun", *IEEE Trans. Magnetics*, 20 (2), 1984, pp 211-214.
15. A. Pokryvailo, "Development of long-charge inductive storage systems at SOREQ NRC", in *Proc of IEEE Pulsed Power Conference*, Monterey, CA, 2005, pp 100-103.
16. M Moradpour et al., "Design and optimization feeding source for an electromagnetic launcher", *Tech J Engin& App Sci.*, 2 (S), 2012, pp 491-496.
17. Jack S Bernards, Michel F. Stumborg and Thomas E Jean, "Analysis of a Capacitor –Based Pulsed- Power System for Driving Long- Range Electromagnetic Guns"' *IEEE Trans. Magnetics*, (39) 2003, pp 486-490.
18. Pradeep Kumar V et al, "Design and development of 4MJ capacitor bank based pulsed power system for electromagnetic launcher", *IEEE Trans, Plasma Science*, 47(3), 1681-1688, Mar 2019, pp 1681-1689.
19. Xiaolong Guo et al.; "Influences of electric parameters of pulsed power supply on electromagnetic railgun system"; *IEEE Trans. Plasma Science*, 43(9), 2015, pp 3260-3267.
20. F. T. Warren et al; "Development and miniaturization of high-charge transfer switches and high-current pulse shaping inductors", *Proceedings of 8th IEEE Int. Pulsed Power Conf* , Jun. 1997, pp 63–61.
21. Robert Kratz, Peter Wyder; "Principles of Pulsed Magnet Design", Springer; NY (2002) pp 60.
22. Hans J. Schneider-Muntau, Jack Toth, and Huub W. Weijers, "Generation of the highest continuous magnetic fields", *IEEE Trans on Appl. Superconductivity*, 14(2), June 2004, pp 1245-1251.
23. Psyk Verna et al., "Advanced coil design for electromagnetically pulsed technologies", ISBN: 978-3-86776-441-4, 2014, pp 289-294.
24. Oleg Zaitov and Vladimir A. Kolchuzhin, "Bitter coil design methodology for electromagnetic pulse metal processing techniques"; *Journal of Manufacturing Processes*, 16 (4), 2014, pp 551–562.
25. Yong Ren et al, "Development of a superconducting magnet system for microwave application", *IEEE Trans. Appl Superconductivity*, 20 (3), 2010, pp 1912-1915.
26. Dylan O. Sabulsky, Colin V Parker, Nathen D Jemelke and Cheng Ching, "Efficient continuous-duty bitter-type electromagnets for cold atom experiments", *Review of Sci. Instr.*, 84, 2013. doi: 10.1063/1.4826498
27. Gaurav Kumar et al, "A computational electromagnetic solver for static analysis of fields and structural design of pulsed power components of electro magnetic launcher"; In the *Proceedings of National Conference On Advances In Armament Technology (NCAT 2018)* at Pune, India, 2018.

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