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FEASIBILITY STUDY OF ELECTROMAGNETIC AIRCRAFT LAUNCHING SYSTEM (EMALS) BY USING ADVANCE ANALYSIS TOOLS.

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***Abstract*— The purpose of this paper is to use the Lorentz force to generate repulsion forces to drive aircraft in a short runway. Other aircraft launching systems like steam catapult, electromagnetic linear motor are going to be less used due to their drawbacks. Lorentz force is used to generate the repulsion in between the rail track which forces the armature in forward direction. For this application, the objective is to pull the large load, such as the aircraft, in a linear motion at a sufficiently high speed, where it can take off easily from a short runway. The approach of electromagnetic aircraft launch system is to the significance for safety and efficiency of aircraft-carrier system. Simulation is carried out by using the analysis software LS-Dyna.**

Keywords—: Lorentz force, LS-Dyna, Electromagnetic Catapult, Simulation, Magnetic field

I. INTRODUCTION TO EMALS

Aircraft launching system from the ship has been employed for over 100 years, and is very important part of the defense capability of every country. Linear motion is used for this purpose. The electropult is first constructed by the USA during world war II and launch a 4.5-ton aircraft successfully. But electropult system design is too costly so it was overtaken by the British Steam catapult invention. The concept of double sided linear induction motor and power electronics led to better launcher development. And it's having a better advantage over a steam catapult. Now days' electromagnetic aircraft launching system is present in both the USA and UK.

India is totally surrounded by the Indian ocean. It shears the longest sea line if 7500km among other nations that shears the Indian ocean. India's 80% export business are done by using the sea and also 85% of oil and gas is imported by using the sea route. The development of India's industrial, commercial and political growth has no meaning until it's got security from the sea side. Therefore, in order to achieve this, it needs a safe sea environment. After the end of cold war, most conflicts have occurred around and in the Indian ocean. Indian navy playing a more important role to keep an Indian ocean sea link safe and peaceful. And to meet this all needs it's necessary to build a great and strong naval force.

India has been adding a new aircraft and system in its air power, new technology upgradation is very important at specific times. The Indian naval aircraft carrier is very important part of naval army and it's required to have every launching system to launch upcoming naval aircraft like Rafale. Every aircraft needs a specific speed to take off within an end of the track. For that purpose, maximum trust is necessary while launching an aircraft. Depending upon the weight of the aircraft and trust produced by the engine, the track length varies for different type of aircraft. For that purpose, Normal track design according to accommodate different launching of aircraft. [1-2]

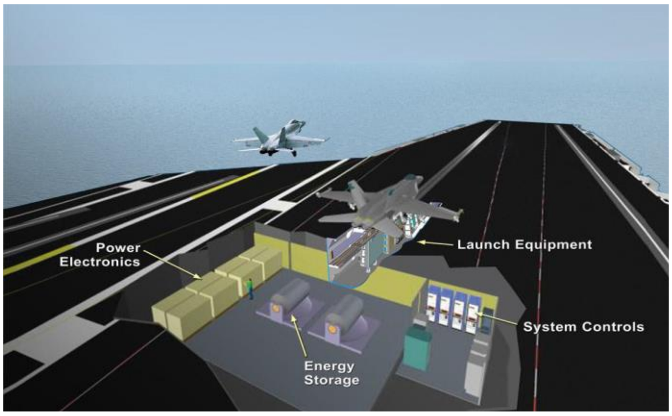


Fig 1. Aircraft Launching system

The normal aircraft track is about 5000 to 6000 feet while on the aircraft carrier it's Very small up to 300 feet only. So it's always necessary of external instruments for the launching of aircraft from a carrier within the end of track length. This requires the aircraft faster speed to get a lift in a small distance of the track. The engineers design the track and instrument to accelerate the aircraft from 0 to 250km/hour in just 2 seconds. The launching system is mainly affected by the weight of the aircraft, capabilities and other parameters like wind, friction and movement of the aircraft carrier. All these conditions can be easily sustained by the electromagnetic launching system on the carrier. India has planned to adapt this system from USA in feature. [3]

Unlike ground based air operations, where a fixed wing aircraft uses required length of runway for takeoff/ landings, the same cannot be replicated on board a ship. Due to the space restrictions, various types of assisted take off/ landings are resorted to. The history of assisted take offs is as old as the invention of aircraft. In 1904, the Wright Brothers used a weight and derrick styled catapult system to assist launch of their early aircraft. The credit of first catapult launch goes to Lt. Ellyson who, in 1912, took off in a naval aircraft from a coal barge. Assisted Take off Systems: CATOBAR & STOBAR

II. WORKING PRINCIPAL OF EMALS

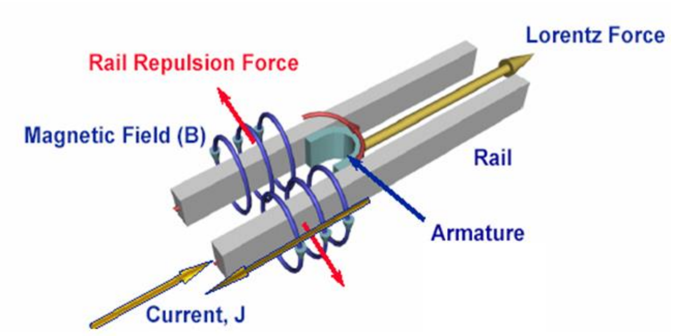


Fig 2. Electromagnetic launching system schematic

A) Electromagnetic aircraft launching system

Figure 2 shows the schematic of Electromagnetic launching system. Current source (J) passes through rails and armature/projectile it forms a closed loop and creates magnetic field and generates Lorentz Force.

The electromagnetic launch system is used to launch projectiles over a speed of 220 km/hours. The technology developed few decades before, but the mechanism is simple but calculations are so complex that, it still needs to be discussed for practical use. A rail uses a flow of current to generate Lorentz force on armature and hence accelerating it to high velocities. As rail does not used chemical combustion to fire the projectile, it is very useful for all branches of defense.

The magnetic field generates Lorentz force on each part of rail in outward direction. The rails of system are fixed rigidly. The armature of rail is moving freely in between two rails with the sufficient contact to pass the current through it. Hence Lorentz force acting on armature accelerates it in forward direction.

B) Lorentz Force

A simple apparatus demonstrates that something weird happens when charges are in motion: If we run currents next to one another in parallel, we find that they are attracted when the currents run in the same direction; they are repulsed when the currents run in opposite directions. This is despite the fact the wires are completely neutral: if we put a stationary test charge near the wires, it feels no force.

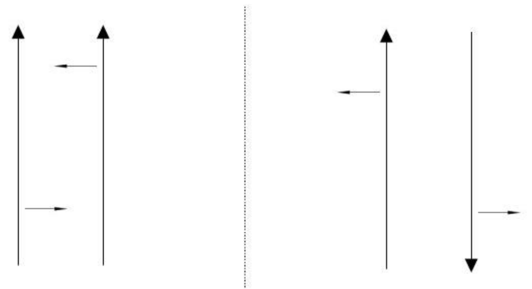


Fig. 3 Left: Parallel current attract. Right: Anti-parallel current repel

Furthermore, experiments show that the force is proportional to the currents — double the current in one of the wires, and you double the force. Double the current in both wires, and you quadruple the force. This all indicates a force that is proportional to the velocity of a moving charge; and that points in a direction perpendicular to the velocity. These conditions are screaming for a force that depends on a cross product.

Lorentz force acting on armature is given by,

$$F = \frac{1}{2} J^2 L' \qquad (1)$$

Where,

F = Lorentz force

J = Current passing through rail

L' = Self-inductance of rail

Practically it is very difficult to generate high current with today's available instruments hence high discharge capacitor bank is used to discharge high current in very less time. If time required to charge the capacitor is more than two or more capacitor banks can be used for rail to reduce the time between two consecutive fires of projectiles. [4-5]

III. MESHING OF EMALS BY USING HYPER-MESH

Magnetic rails are important component of the EMAL system. Length of this rail may be depend on the aircraft carrier runway length which is around 100 to 120m. Copper is the material which is used for the magnetic coil. Contact area between the magnetic coil and the hook should be circular so we can get the more area in contact and smooth movement will be possible than the rectangular contact area. Also the stress generation in circular area will be distributed over the all contact area. Capacity of magnetic rail to sustain the energy near about 10MJ. As it required to pull 15Tonne load of the aircraft.

Meshing of this component is Hexa 3D meshing as it is solid component. Following is the criteria used for the meshing of magnetic rail track. Maximum 5% tri elements are allowed in meshing of any component.

Meshing Parameter

Meshing type- Mix (Quad+Tria) Meshing

Target element size – 10

Meshing Criteria:

Minimum element size- 5

Maximum element size- 15

Maximum Quad angle- 135

Minimum Quad angle- 45

Maximum Tria angle- 120

Minimum Tria angle- 20

Aspect ratio- 5

Skew- 45

Warpage- 15

% of trias- 5

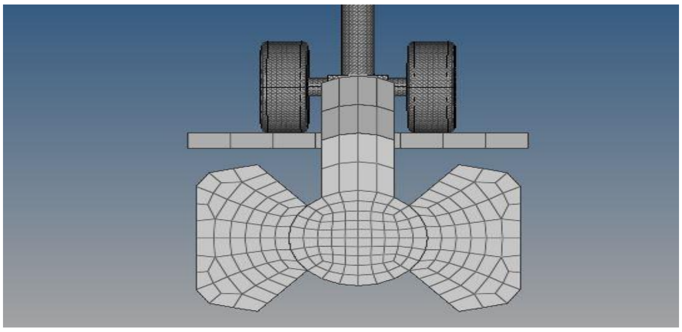


Fig 4. Front view of EMALS meshing

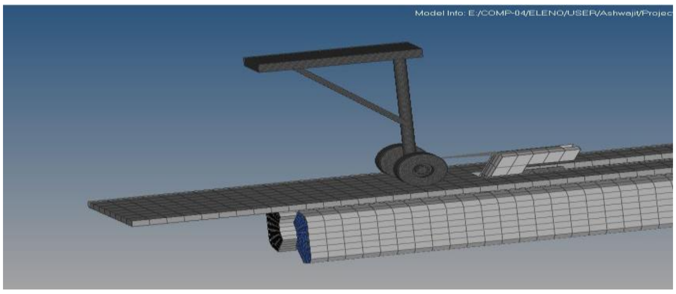


Fig 5. Meshing of EMALS

IV. BOUNDRY CONDITIONS

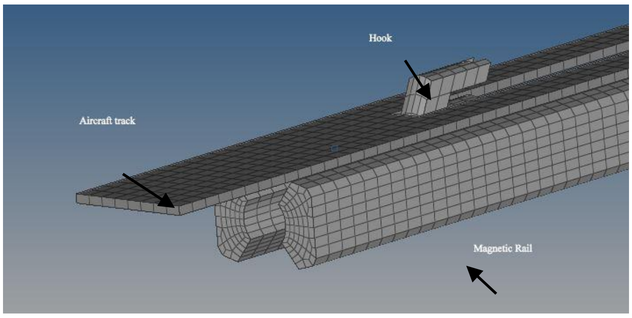


Fig 6. EMALS parts

Rail material is considered as copper and projectile material as aluminum. Card used for this material is - MAT1.

TABLE I. MATERIAL PROPERTY

Material	Density (Kg/m^3)	Conductivity (S/m)	Young's modulus (GPa)
Copper-rails	9800	5.8e7	125
Aluminum-Armature	2640	3.5e7	70

Contact between armature and rails is used as Automatic surface to surface with master as rails and slave as armature and Dynamic surface friction is assumed as 0.1 for them.

Rigid walls are attached to the rails for fixing of rails; also armature is followed by rigid walls for guide in rails. These walls are made up of 2d shell elements with average mesh size as 10mm. Material used for the elements is MAT24.The contact between the armature and rigid walls is Automatic surface to surface. Same contact is used for rigid wall for guide and armature. Surface friction is assumed as 0.1 for them.

Electromagnetic cards are used for solving of electromagnetic equations such as EM_circuit, EM_Solver, EM_control etc.

For solving thermal equations, room temperature is assumed 25^0C. Cards used are Control_Thermal_solver, Initial_Temperature_set etc.

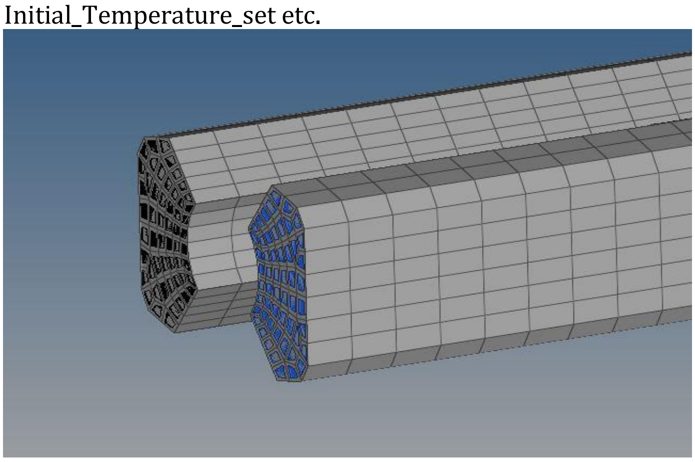
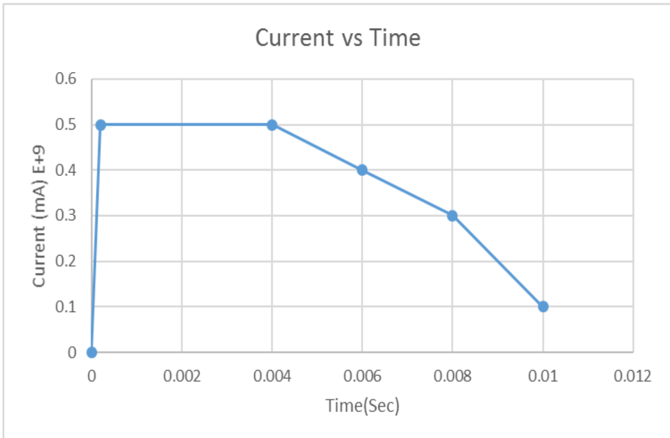


Fig 7. Current Segment

The solution solved for 4 mili-seconds. The time step used for the solution is 0.001 mili-seconds. Binary plots are written at 0.005 mili-seconds.

The peak current used for simulation is 1025kA.The maximum peak of the current is achieved in 0.1ms. Current profile used for the simulation is generated from Maxwell.



Graph 1. Current(mA) vs Time(millisecond)

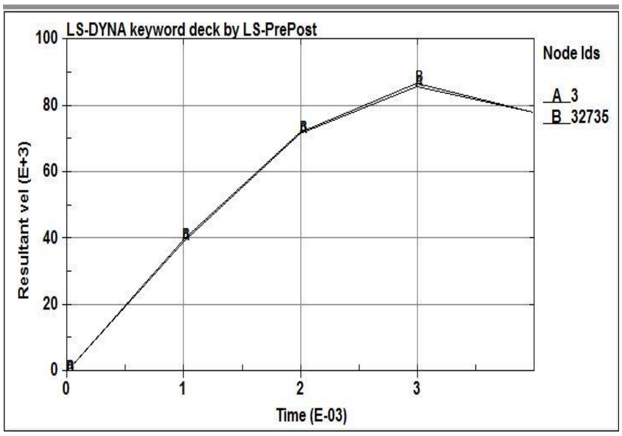
Total time required for solving the run is 26 hours 54 min. 16 sec. with Intel i5 4th generation processor and 4GB RAM computer.

V. ANALYSIS BY USING LS-DYNA

Meshing of the model is done by Hype-Mesh. Average mesh size of the element is 10 mm. Meshing element used for meshing is 3D Hex mesh. After that all boundary condition are given to the component as per the requirements. Surface to surface contact is given between the component. To join the aircraft mass and hook 1D rigid contact has been used. Each part must be assign by the material and property.

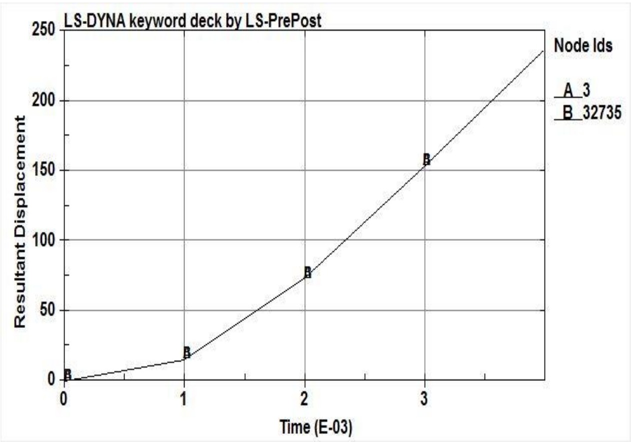
The complete model with all constraint, property and boundary condition is having to convert into .k file format. After that in LS-Dyna that dot k file imported to do the analysis run. After completion of run with normal termination we have to check this result in post processor. For post processing here we use the LS post processing (LSPP) software. Where we get the all result as per our output requirement. It also gives simulation movie of the analysis so it's easy to identify the motion of output.

Initial condition taken for the analysis are- Initial temperature 25^{0}C, External wind turbulence and forces are neglected, Temperature effect also neglected.



Graph 2: Velocity(mm/s) Vs. Time(ms)

The active length of 1.63m is achieved in the 0.003 seconds. The velocity achieved at this time is 288km/hr.



Graph 3: Displacement(mm) Vs. Time(ms)

The muzzle velocity for 2m length railgun is obtained as 288km/hours. Muzzle energy is generated at the point. This energy can be used to pull the target mass.

VI. Conclusion

In this paper, electromagnetic aircraft launching system simulation is done by using LS-Dyna software. Lorentz Force generated in between the rails can be used to pull the mass in forward direction with high velocity. The maximum required velocity for the aircraft or mass can be easily achievable by using the electromagnetic system. So it's very useful for the aircraft to take off within a short runway distance. With the help of force distribution on armature and rails, critical areas can be modified. By using electromagnetic aircraft launching system we can overcome the drawback of steam catapult launching system and aircraft can also get take off easily.

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