Electromagnetic Aircraft Launch System

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ABSTRACT

The concept of using electromagnetic forces to launch an object has been discussed and researched by numerous engineers for decades now, only recently has it become more realizable with advances in technology. The goal of this project is to use electromagnetic forces to propel a payload down a track at a desired velocity for launch. An electromagnetic launch system is one that the harnesses the power of using a large electric current to generate a magnetic field which can push a magnetized cylinder down a channel for launch. The proliferation of electromagnetic launch systems presently being designed, built, or studied, there appears to be no limit to their application.

Keyword: - *steam catapult, EM catapult, LIM, LSM*

1. INTRODUCTION

The current system in place right now by the US Navy uses a steam powered system that pushes two pistons the length of the runway by highly pressurized steam. Some of the disadvantages of this system include the size and weight limitations that the catapult can actually propel. In addition, steam powered catapults impart large transient loads to the airframe and are difficult to maintain. Furthermore, the amount of weight the current catapults are capable of launching limits the types of planes that are compatible with it. The advantages to using electromagnetic catapults are much greater than current systems in place it will be the goals of this project to further explore these possibilities. The steam powered system can launch a 45,000 pound plan from 0 to 165 mph in only two seconds under the distance of 100 yards. Our goal will be to modify the same design for an electromagnetic launch and receive similar speeds on a smaller scale instead.

2. PRESENT STEAM CATAPULTS

The existing steam catapults currently installed on U.S. carriers consist of two parallel rows of slotted cylinders in a trough 1.07 m deep, 1.42 m wide, and 101.68 m long, located directly below the flight deck. Pistons within these cylinders connect to the shuttle which tows the aircraft. The steam pressure forces the pistons forward, towing the shuttle and aircraft at ever increasing speed until takeoff is achieved. While the catapult has many years of operation in the fleet, there are many drawbacks inherent in the steam system. The foremost deficiency is that the catapult operates without feedback control. With no feedback, there often occur large transients in tow force that can damage or reduce the life of the airframe. Also, extra force is always added due to the unpredictability of the steam system. This tends to unnecessarily overstress the airframe. Even if a closed loop control system was added to the steam catapult, it would have to be highly complex to significantly reduce the thrust transients to a reasonable level. Other drawbacks to the steam catapult include a high volume of 1133 m3, and a weight of 486 metric tons. Most of this is top-side weight that adversely impacts the ship's stability and righting moment. The large volume allocated to the steam catapult occupies "prime" real estate on the carrier. The steam catapults are also highly maintenance intensive, inefficient (4-6%), and their availability is low. Another major disadvantage is the present operational energy limit of the steam catapult, approximately 95 MJ9+. The need for higher payload energies will push the steam catapult to be a bigger, bulkier, and more complex system.

3. THE ELECTRO-MAGNETIC CATAPULT

As hydraulic catapults gave way to steam in the 1950s, so the early years of the new millennium have seen the development of an alternative technology for launching aircraft, the electro-magnetic (EM) catapult. EM catapults are powered not by a steam driven piston but by linear induction motors or LIMs. Linear induction motors work on the same basic principle as all induction motors except that the motor is effectively unrolled to provide a linear stator and rotor. The movement of the armature or rotor through stator's electric field is thus linear rather than angular or rotational. This is well proven technology; the principle was first demonstrated in the military field in 1944 when the Luftwaffe tested a LIM- powered anti-aircraft gun. LIMs have since been used to power monorails at Euro-Disney in Paris and on Vancouver's rapid-transit system; they have also been used to drive roller coasters into the 160 kph range and an experimental LIM- powered train has achieved 400 kph. The USN is currently developing the Electro Magnetic Aircraft Launch System (EMALS) for installation in the USS Gerald R Ford (CVN-78), the first of its new generation of super carriers. This is a particularly interesting development as the USS Ford will be nuclear powered and thus has abundant steam available for conventional steam catapults. Despite this, the USN has chosen to develop EM technology. An EM launch system offers the requisite higher launch energy as well as substantial improvements in areas other than performance. These include reduced weight, volume and maintenance, and increased controllability, availability, reliability and efficiency. The ability of an EM system to vary speed and thrust to meet the needs of the vehicle being launched makes a single catapult suitable for a wide range of airframes, both manned and uninhabited.

Fig -1: first carrier to be built with an electromagnetic catapult

4. EASE OF USE

For the design that is being used for this project contains a rectifying circuit for charging of the capacitors. The capacitors that are being used in this application are two 250V 12,000μF which are not capable of being fully charged by a regular power supply. In order to fully charge the capacitors the charging circuit will contain several voltage doublers to give enough voltage to charge the capacitors. Once the capacitors are charged they amount of charge will be monitored in LabView by using a voltage divider and scaling the low voltage in LabView appropriately to give an accurate reading. The amount of charge stored in the caps will vary depending on the amount of weight that is trying to be launched. Attached in between the capacitors and coil is a 4 layered PNPN SCR (Silicon Controlled Rectifier) which is triggered by a lower voltage of 1.7V. When the lower voltage is applied at the gate of the SCR the current from the capacitors passes through the PNPN junction and flows through the coil. When current is flowing through the coil it generates a magnetic field around the piston that has an opposing magnetic charge of the coil repelling it through the channel at very high speeds. Several switches are used in the circuit for safety including a charging switch and firing switch. The control system for this project will all be done through LabView which will apply the 1.7V to gate of the SCR to trigger the device. In addition to triggering the SCR, LabView will also be responsible for determining how much charge the capacitors will hold depending on how much weight is being launched by thresholds set in the program.

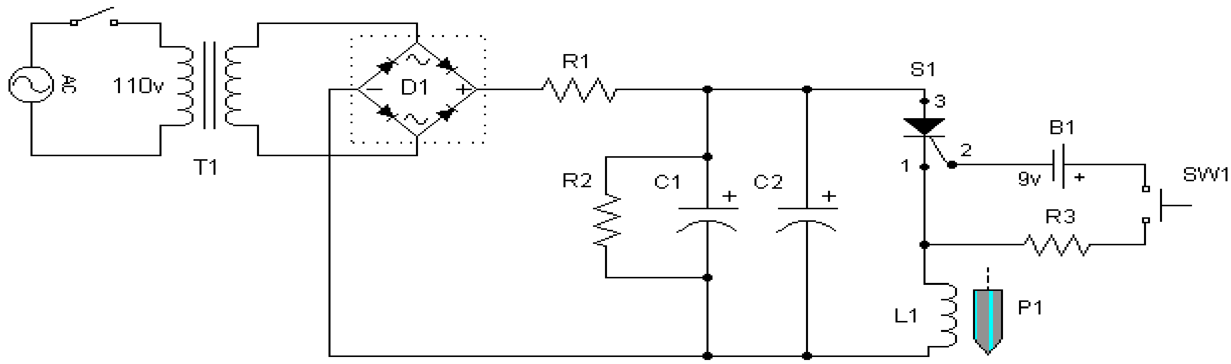

Fig -2: circuit diagram of EMALS

5. EM AIRCRAFT LAUNCH SYSTEM – EMALS

The requirements of the EMALS are driven by the aircraft, the carrier, and the operational requirements of the carrier's air wings. These requirements are:

Table -1: EMALS Requirements

End speed	28-103 m/s
Max peak-to-mean tow force ratio	1.05
Launch energy	122 MJ
Cycle time	45 seconds
Weight	< 225,000 kg
Volume	< 425m^3
End speed variation	0 to 105 m/s

The present EMALS design centers around a linear synchronous motor, supplied power from pulsed disk alternators through a cycloconverter. Average power, obtained from an independent source on the host platform, is stored kinetically in the rotors of the disk alternators. It is then released in a 2-3 second pulse during a launch. This high frequency power is fed to the cycloconverter which acts as a rising voltage, rising frequency source to the launch motor. The linear synchronous motor takes the power from the cycloconverter and accelerates the aircraft down the launch stroke, all the while providing "real time" closed loop control.

6. THE CHALLENGE

The challenge of this project will be to get the projectile up to a fast enough speed in a short distance. Using a coil gun for this type of application can improve the current design of steam catapults for several reasons. For example, by increasing the amount of current in the coil at the end of the track the speed of the launch will be proportionally increased. In addition, this design will reduce the amount of stress on the frame the aircraft carrier. Currently the United States Navy is working on a similar idea called the Electromagnetic Aircraft Launch System or EMALS which uses a similarly concept. For this project we will be using several capacitors wired in series to produce the necessary amount of current in our coil. Since the navy launches 45,000 lbs aircrafts the amount of energy storage that is needed is much larger and using lots of capacitors is impractical. The EMALS energy-storage subsystem draws power from the ship and stores it kinetically on rotors of four disk alternators. Each rotor can store more than 100 mega joules, and can be recharged within 45 seconds of a launch, which is much faster than steam catapults. This type of energy storage is ideal for this type of application but since we will be doing a small scale capacitors will do. Another problem that is faced during projects like this is being able to complete a circuit with such high current. This same problem occurred when testing this project being that the SCR used could only handle 35A which is not nearly as much as the capacitors can discharge. Since the 1 SCR can't handle the amount of current that we pass through it. In order to combat this issue the use of multiple SCR's that are triggered at the same time which allows for the current to be divided through each SCR reducing the chance of a single one failing. Another challenge while using the SCR's was that even if it can take the amount of current running through it the heat that it generates is very high which is why a heat sink was added to the original design lower operating costs.

7. STRENGHT OF EMALS

The EMALS will replace the current generation of electromagnetic catapults this will switch to:

- Lower operating costs.
- Require fewer people to operate.
- Improve catapult performance expand the range of manned and unmanned aircraft that the aircraft carrier can launch.

8. SHIP IMPACT

The introduction of EMALS would have an overall positive impact on the ship. The launch engine is capable of a high thrust density, as shown by the half scale model that demonstrated 1322 psi over its cross section. This is compared to the relatively low 450 psi of the steam catapult. The same is true with energy storage devices, which would be analogous to the steam catapult's steam accumulator. The low energy density of the steam accumulator would be replaced by high energy density flywheels. These flywheels provide energy densities of 28 KJ/KG. The increased densities would reduce the system's volume and would allow for more room for vital support equipment on the host platform. Another advantage of EMALS is that it would reduce manning requirements by inspecting and troubleshooting itself. This would be a significant improvement over the present system, which requires substantial manual inspection and maintenance. The EMALS, however, will require a transition of expertise from mechanical to electrical/electronic. EMALS eliminates the complexity of the present system's conglomeration of different subsystems. The steam catapult uses about 614 kg of steam for a launch, it uses hydraulics extensively, water for braking, and electromechanics. These subsystems, along

With their associated pumps, motors, and control systems tend to complicate the launch system as a whole. With EMALS, launching, braking, and retraction would be achieved by the launch motor, thereby reducing all the auxiliary components and simplifying the overall system. The hydraulic oils, compressed air, etc. would be eliminated as well as the cylinder lubricating oil that is expelled into the environment with each shot. The EMALS would be a stand alone system, completely independent of the ship's main plant. This will allow greater flexibility in the design of the ship and more efficient ship propulsion schemes. One of the major advantages of electromagnetic launch is the ability to integrate into the all electric ship. The Navy has directed substantial research into its Advanced Surface Machinery program that is developing electric derived propulsion schemes for the next generation of surface combatants. There has also been a good deal of work in high power electric weapon systems. As such, more and more of a ship's systems will evolve into the electrical power levels off the grid should not be a problem in an all electric ship, considering multi megawatt pumps already exist on carriers for various applications. Perhaps the most interesting aspect of electromagnetic launch is the flexibility it offers in the way of future aircraft and ship designs counterparts of old mechanical systems. This is true of the launch, and eventually, the arresting gear. The average power required by EMALS is only 6.35 MVA. Taking these. An electromagnetic launcher could easily be sized down to perform as a launch-assist system, augmenting the short takeoff of a STOVL aircraft. It can also be easily incorporated into the contour of a ramp, which provides a more efficient fly-away angle for the aircraft being launched. This reduces the required end speed, the commensurate energy supplied, as well as the stresses on the airframe. Overall, an EM launcher offers a great deal of flexibility to future naval requirements and ship designs. On the other hand, there are drawbacks to the EMALS. One of these is that high power electromagnetic motors create electromagnetic interference (EMI) with electronic equipment. As in the case of an electromagnetic launcher, there would be sensitive aircraft equipment sitting directly above the launch motor. Along with the aircraft equipment is the ship's own equipment, which may be affected by the electromagnetic emissions. Through proper EMC design and a "magnetically closed" motor design, EMI will be minimized.

Another drawback of an electromagnetic launcher is the high speed rotating machinery associated with pulsed power applications. The disk alternator rotors are spinning at 6400 rpm, each storing 121 MJ, for a total of 484 MJ. In a laboratory, this is not a problem, but put these rotors on a heaving, jarring platform and it becomes more complicated. In order to ensure safe operation, the flywheel and bearings are to be a stiffer design than conventional.

9. CONCLUSION

We conclude that the EMALS is a very good solution, being surprisingly small and simple , with a manageable power electronics switching system. The steam catapult does not appear to provide sufficient advantage to make the extra complexity worthwhile, unless becomes a much more significant concern that has so far appeared. However there will be advantages in the power electronic system. The EMALS offers the increased energy capability necessary to launch the next generation of carrier based aircraft. Improve catapult performance expand the range of manned and unmanned aircraft that the aircraft carrier can launch. The challenge of this project will be to get the projectile up to a fast enough speed in a short distance.

6. REFERENCES

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