AN INTEGRATED MACHINE AND MATRIX CONVERTER BASED HIGH POWER RUDDER EMA

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Abstract

This paper describes the design, construction and testing of an integrated Electro-Mechanical Actuator (EMA) using a Permanent Magnet Motor drive by a Matrix Converter. The design of the integrated system has included the motor, the power converter and the thermal integration with the EMA. The system has been designed to meet the operating requirements of a large rudder actuartor. Practical results from the converter under test are presented for a range of conditions.

1 Introduction

This paper describes the design and construction of an Integrated Electro Mechanical Actuator (EMA) intended as a technology demonstrator for a rudder actuator on a large civil aircraft.

The rudder application, shown in fig. 1, has been chosen for this technology demonstrator due to the interesting operating characteristics of the surface, particularly the thermal issues when the surface is held in the air stream during an engine-out condition. In safety critical applications such as this it is important to use natural cooling where possible, and this work is premised on the assumption that only natural cooling is excitable in the application. If forced cooling was permissible, as it would be in many industrial applications, it may be possible to make the complete system more compact, but at the cost of an additional single point failure mechanism.

An Electro-Mechanical Actuator (EMA) has been chosen for this project, where an electric motor is used to mechanically move flight surfaces via an associated gearbox/ballscrew [1]. When using an EMA

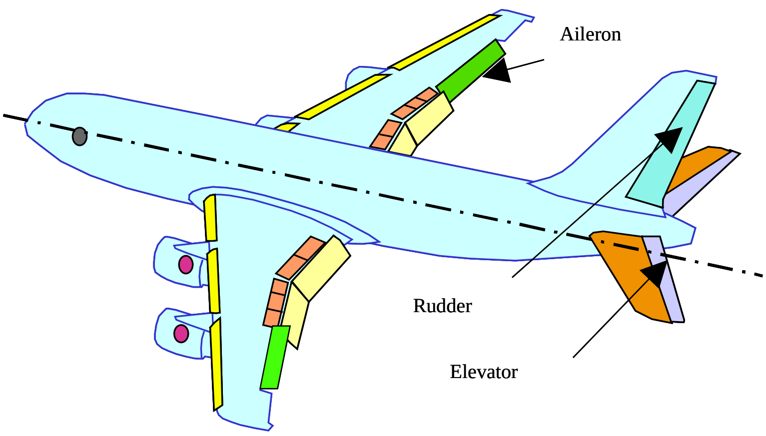

Fig. 1. Flight Surfaces on a Typical Civil Aircraft

there are presently difficulties with the reliability and safety requirements that primary flight surfaces have to meet, but it is expected that these issues will be resolved very soon.

A Permanent Magnet motor has been chosen for the application due to the benefits offered in terms of size and weight over other traditional types of machine [3]. The Matrix Converter [2], as shown in Fig. 2, has been chosen as the power converter for this application due to the advantages in size and weight [4]. This, in conjunction with the absence of the requirement for electrolytic capacitors, recommends this topology for aerospace applications.

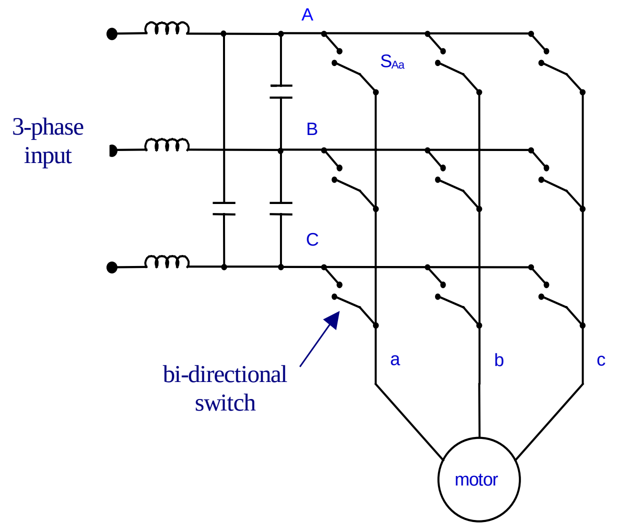

Fig. 2. The Basic Matrix Converter Circuit

2 Integrated EMA and Drive

Fig. 3 shows the integrate EMA concept, with the electronics mounted on the ballscrew cover and the motor attached directly to the gearbox drive shaft. There are three main feedback loops required for the control of the actuator:

- Ram position (aileron surface position)
- Motor speed (pump speed)
- Converter Output current (in a closed loop vector control scheme for the motor)

These three control loops can be seen diagrammatically in Fig. 4. The motor speed is controlled using a typical vector control scheme [3]. The motor and position control for the system and the Matrix Converter modulation strategy, a space vector modulation strategy [6] is implemented on a DSP (The Texas Instruments C6711). This is connected to the A to D converters via a FPGA. This FPGA also handles all the three-step output current direction based current commutation strategy for the Matrix Converter [5] and the generation of the control signals for the IGBTs in the Matrix Converter circuit.

3 Permanent Magnet Motor

Fig. 5 shows the stator, rotor and complete motor. This motor was then mounted onto the actuator housing for testing. The motor is designed for a nominal speed of 5000rpm to match the characteristics of the actuator. The size of the cooling fins on the stator housing of the motor is determined by the steady state loading conditions of the rudder in an engine out condition. This conduction is far more thermally challenging than any other operating mode of the rudder because 50% torque has to be maintained at zero motor speed for a number of hours.

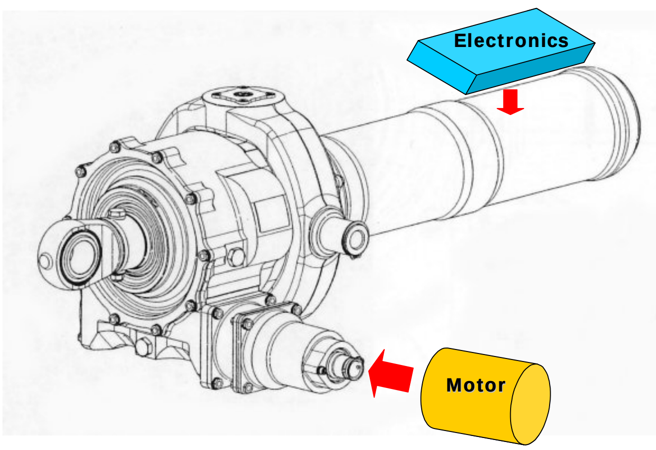

Fig. 3. The Integrated EMA Concept

4 The Demonstration Matrix Converter

Fig. 6 shows the Matrix Converter mounted on the custom designed heat sink. The heat sink, device modules, gate drives and input filter capacitors can clearly be seen.

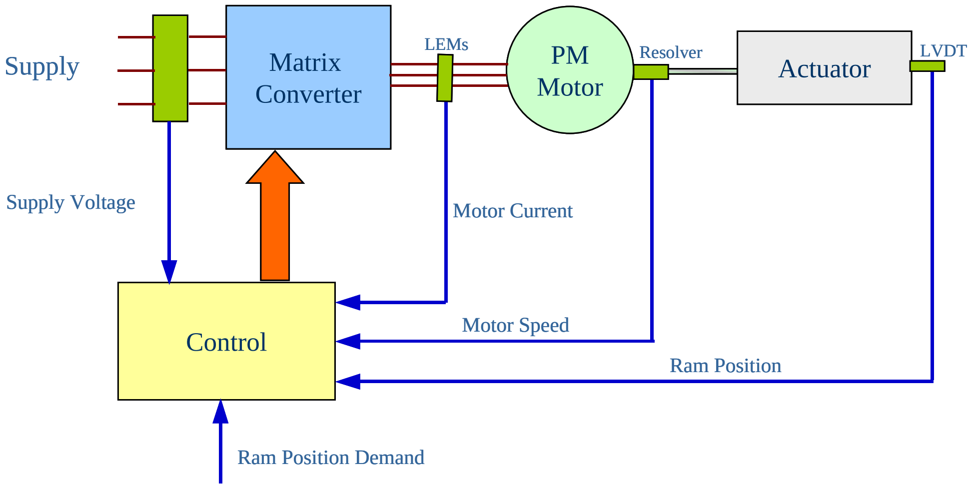

Fig. 4. The EMA and Matrix Converter Control Loops

The heat sink is integrated into the ball-screw housing, shown in Fig. 7, and has been designed to operate over all the required conditions. This heat sink was designed with the use of CFD simulation techniques. The simulation results have been verified using practical measurements, such as those shown in the thermal image in Fig. 7.

The Matrix Converter uses custom designed power modules that have been built to aerospace standards. One of these power modules is shown in Fig. 8. Each module contains all the devices required for one output leg of the Matrix Converter, leading to a very compact design with low inductance between devices on the same output leg of the converter, as shown in Fig 9. The three terminals for the input voltages and one for the output connection can be seen.

Each module is rated at 600V and 300 Amps. The complete converter is rated at 30kW from a variable frequency (360Hz to 800Hz) 3-phase, 115V Line to Neutral aircraft supply.

There are a number of protection issues associated with any Matrix Converter application. The Matrix Converter circuit has no freewheeling paths as found in a conventional inverter. Therefore it is not possible to simply turn off all the devices, as you would in an inverter, without providing an alternative path for the current as this action will open circuit the inductance of the motor causing a high voltage transient.

To provide a current path when the switches are disabled a clamp is provided in the form of a diode bridge across the input and output lines of the converter, as shown in Fig. 10. A small capacitor and dissipation chopper with a resistor are used for this clamp circuit, which is rated to take the energy stored in the inductance of the motor without exceeding the maximum voltage rating of the devices.

Fig. 5. The Permanent Magnet Motor

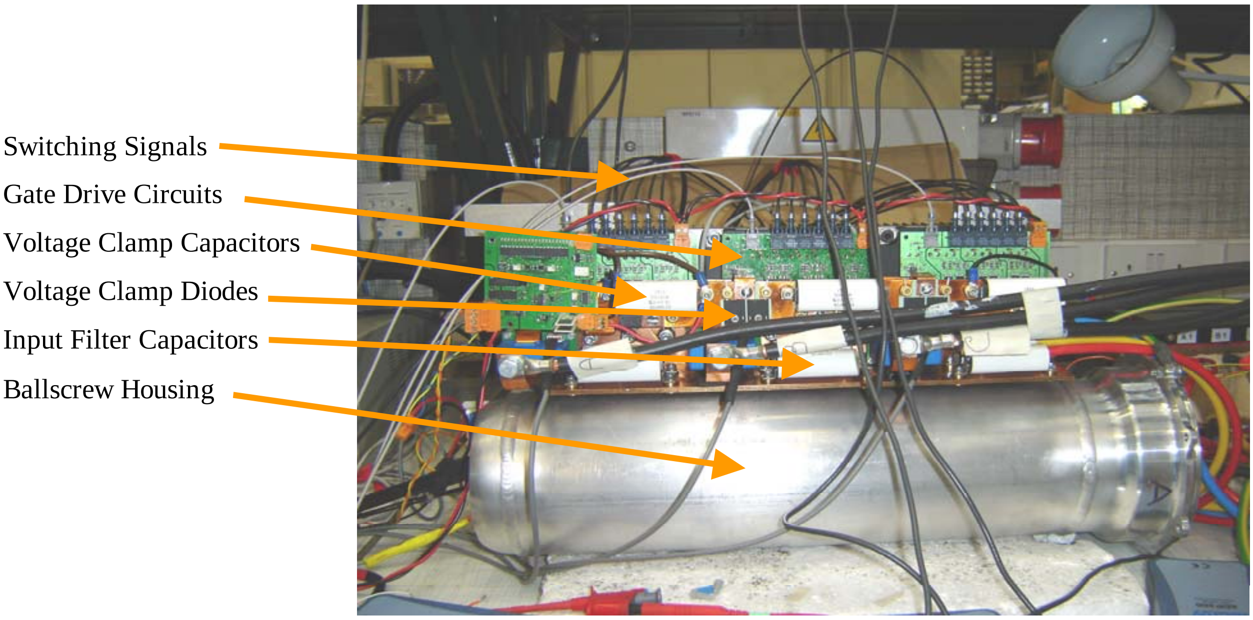

Fig. 6. The Matrix Converter and Integrated Heat Sink

In a fault situation, or when a loss of supply is detected, all the devices of the Matrix Converter are all turned off and the over-voltage clamp is used to avoid destruction of the devices due to over-voltage transient.

Output over-current detection is implemented in both hardware and software on the control platform using measurements of the three output currents. These current measurements are also required for the machine control, so no additional hardware is required. There are a number of possible fault conditions within the Matrix Converter and its control. If there are problems with the control functionality then it will be caught by the output over-current trips.

One of the other potentially source of an internal failure is if there is a problem with the output current direction based commutation strategy [4]. If the current direction detection fails then there is the potential for short-term open circuits to appear on the output of the converter every time the state of the switches is changed. This causes energy to be passed to the clamp capacitor; the voltage on the capacitor then slowly rises.

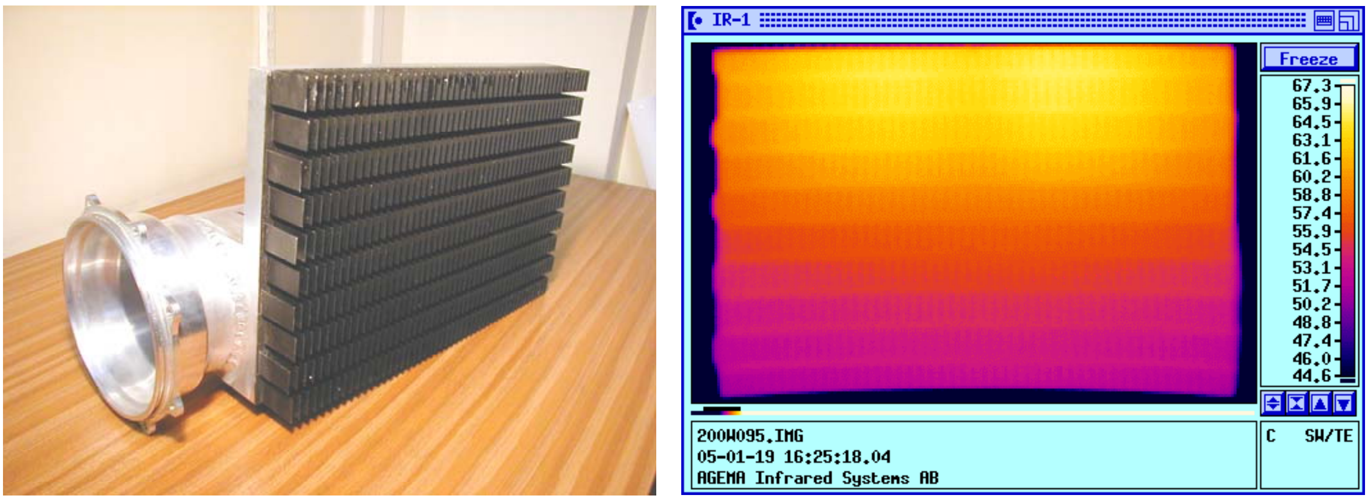

Fig. 7. Heat Sink with Integrated Ball-screw Housing and associated Thermal Image

Fig. 8. The Matrix Converter Power Module

A voltage detection circuit is used to monitor the voltage across the clamp capacitor and this trips the converter if the voltage rises above a pre-set limit. This detection mechanism will also detect a gate-drive or device fault that leads to a failure of a device to turn-on.

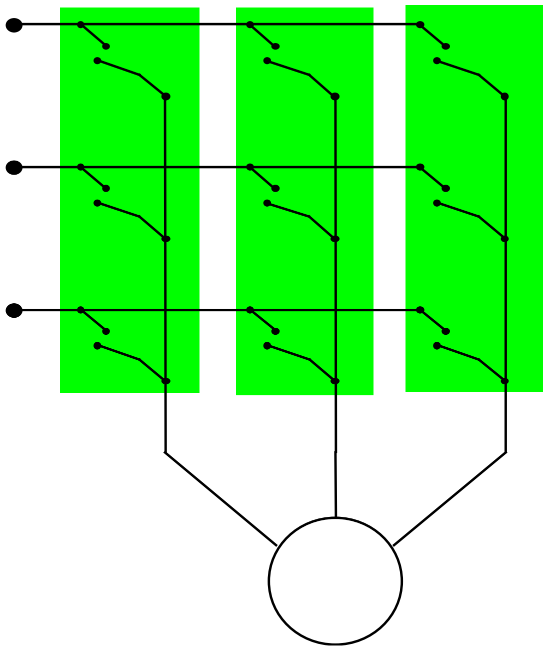

Fig. 9. The Arrangement of the Matrix Converter Power Modules

4 Practical Results

A Matrix Converter Permanent Magnet Motor Drive for an Electro-Mechanical Aircraft Actuator has been designed and built. The system has been tested on an aircraft actuator loading rig, with tests performed over a range of operating scenarios.

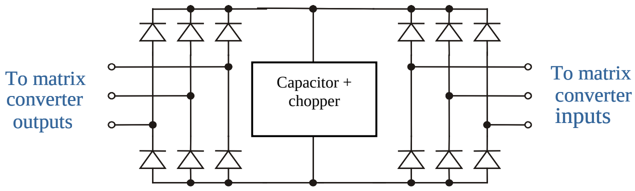

Fig. 10. The Matrix Converter Clamp Circuit

Figure 12 shows the operation of the Matrix Converter acting as a permanent magnet motor drive. The results in this figure demonstrate the converter acting as a motor control system with a speed reversal from 1000rad/sec to –1000rad/sec. The target speed, the actual motor speed from the revolver output and the motor currents are shown for the converter operating with a torque producing current, $i_{q,ref}$, limit of 100Amps.

With the actuator connected to a suitable loading rig the actuator can be tested against a set of realistic operating conditions. An example of this is shown in Fig 13 for the actuator undergoing a step response in position demand under a standing load of 30kN. In this example a torque producing current limit of 80Amps and a motor speed limit of 2500rpm have been applied.

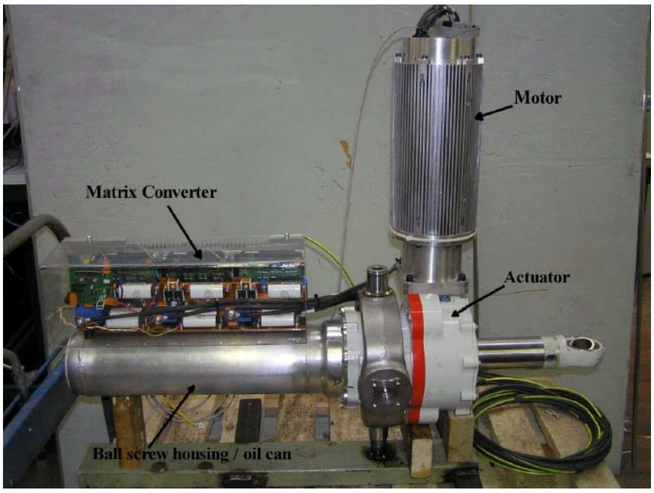

Fig. 11. The Complete Integrated Actuator with Power Converter and PM Motor

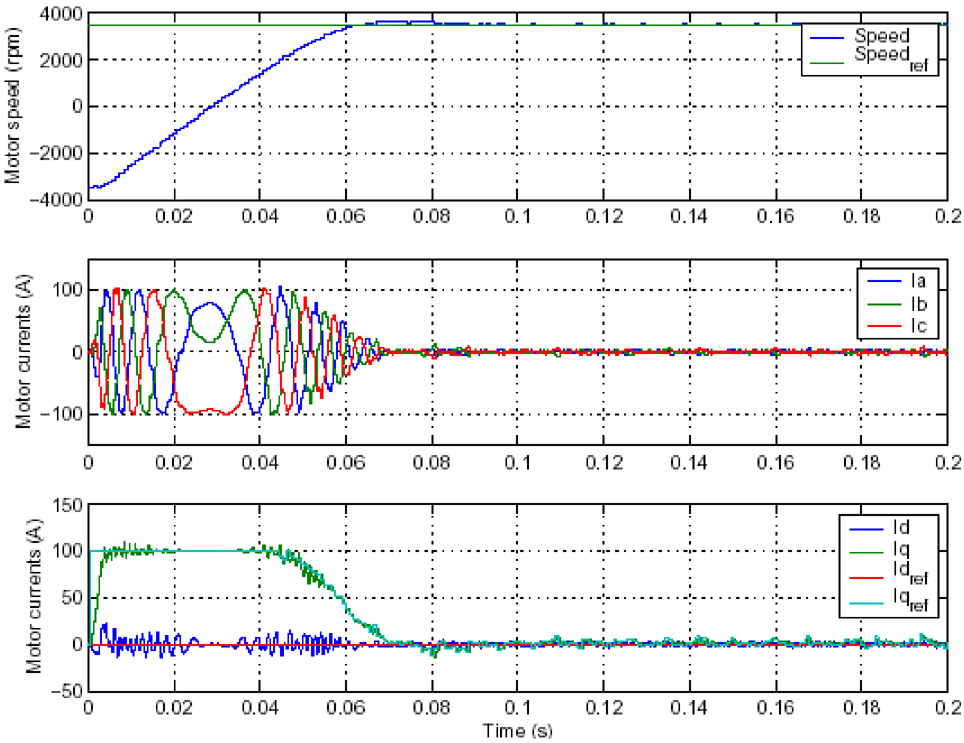

Fig. 12. The Matrix Converter Output Current and the Motor Speed during a Motor Speed Reversal Test

4 Conclusions

This paper has demonstrated the design, construction and operation of a Matrix Converter Permanent Magnet Motor Drive for an Electro-Mechanical Aircraft Actuator. The Matrix Converter is used as a vector controlled motor drive. The project has demonstrated that this type of advanced 'more electric' actuation is achievable and practical with a truly integrated thermal and electrical machine, converter and actuator design.

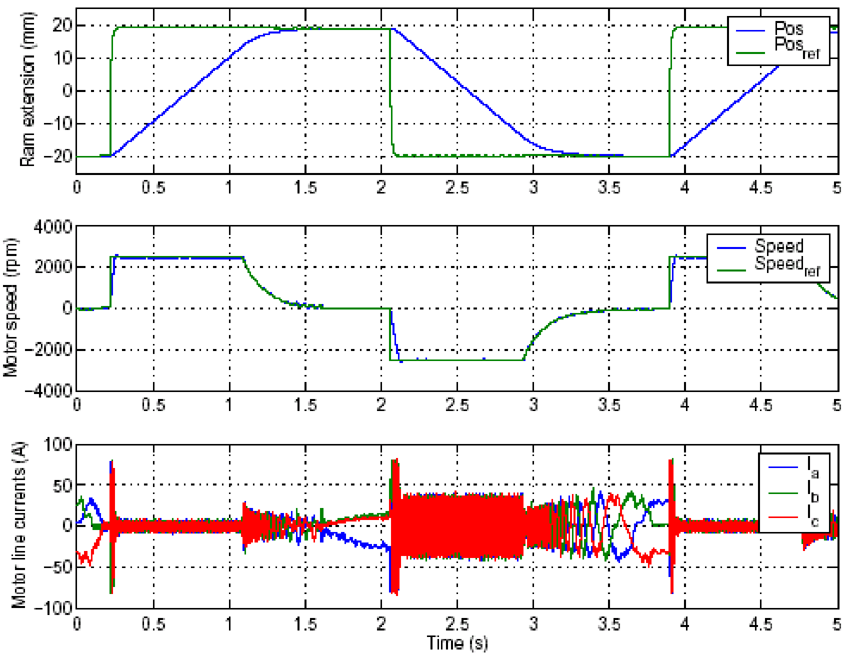

Fig 13. Actuator Response to a 40mm Square-wave Position Demand

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