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Prevention of Tail Rotor Crash by using Modern Electrical and Electronic Devices

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Abstract: Aviation industry's main objective is to provide a safer air travel. The factor of safety for aircrafts should be high enough to sustain safer operation. Of all the aircrafts, rotorcrafts have less factor of safety because of its numerous moving parts like rotors, transmission units etc. The failure of tail rotor due to constant wear and fatigue in mechanical transmission units has resulted in helicopter crashes. Employment of simple Electrical Stator-Rotor Assembly along with Electronic Devices and systems can overcome this intricacy. This can be achieved by electrically driving the tail rotor with the help of microcontroller for voltage variation. This reduces vibration, noise and weight with easy maneuvering. Moreover the effect of torque can be utilized for directional control. Further implementation of sensors and digital fly by wire system makes it to be used for unmanned operations with full automation.

Keywords: Drive trains, microcontroller, sensors, switch-over circuit, tail rotor, torque reaction.

Introduction

Helicopters or rotorcrafts are the light and fast moving flying transporters with vertical take-off and landing (VTOL). It provides effective means of transporting people, material and equipment in different environments. They mainly depends on their rotor systems for lift creation. There are two (also one) rotor configuration that can be seen in a helicopter. One is the main rotor, which provides most of the lift, and a tail rotor for torque and directional control. Both of these rotors should work properly to achieve better performance and good characteristics. Though many other anti-torque systems has been in existence, tail rotor is the most widely recognized anti-torque system. This tail rotor is driven by mechanical linkages from the main power plant through a complex system of shafts, gears and couplings. The configuration requires intensive maintenance and continuous monitoring for signs of possible failures. Air crash investigation says that two thirds of helicopter crashes are due to failure in power transmission systems. Of which 33% are mainly due to tail rotor failure. The contributing factors for this tail rotor failure are fatigue, wear and transmission links failure.

This failure can be prevented in two ways.

- Elimination of the tail rotor, and
- Driving tail rotor through electrical systems.

Elimination of tail rotor is already in existence with fenestron and NOTAR. But driving tail rotor through electrical systems have not been produced. We have found an approach for this electric tail rotor. The tail rotor is made to run by a suitable electric motor powered by rechargeable batteries charged with generators. This electrically driven tail rotor will replace mechanical tail rotor drive shafts, gearboxes and couplings. This electrical system is more efficient than mechanical systems. Also there is less chances for failure with reduction in overall weight, noise and vibration.

Failure analysis

The accident rate in helicopter flight was 7.5 per 100,000 hours of flying, whereas the airplane accident rate was approximately 0.175 per 100,000 flying hours. The causes of helicopter accidents can be grouped into three major types. They are

1. Operational Error
2. Mechanical Malfunction
3. Electrical Malfunction

A. Statistics on Accidents

A statistical report on helicopter crash is so vital to obtain detailed information of the crash. Air crash Investigation Survey has produced many detailed bulletins on the factors on which helicopters accident occurs. Agencies like National Transport safety Board, National Transport Safety Bureau and Air Accidents Investigation Branch etc. has given their reports on helicopter crash.

Rotor operation and statistics report jointly produced by Federal Aviation Administration and International Helicopter Safety Team shows the number of accidents between the years 1982 to 2007 on various factors. Totally 191 accidents were taken into account and analysis were carried out by them. From the above survey (statistics) 26% of helicopter accidents are mainly due to failure in tail rotor transmission units. Loss of power transmission capability in the main module will result in loss of lift and control, both of which can lead to potentially catastrophic accidents. If this 26% of failure is cleared then rotorcraft will have a good factor of safety.

Fromref [5], a table is prepared which gives the complete details of various helicopter accidents related to tail rotor failure.

Table 1. Tail Rotor Failure History

S. No.	Helicopter type & registration	Year	Nature of damage	Investigation findings
1.	Bell 212 OY-HMC	1984	Damage to the aircraft	Failure of the external spline section due to less power
2.	Lynx AH Mk1 XZ204	1987	Aircraft destroyed	Failure of tail gearbox
3.	Bell UH-1B N3979C	1993	Loss of tail boom	Fatigue failure in gearbox attachment bolts.
4.	SA341G Gazelle 1 G-RIFF	1993	Damage to the rotors	TR drive shaft had failed
5.	Sea King HAS Mk6 XV654	1993	Category 4 damage	Shear of tail drive shaft
6.	Wessex HC2 XR524	1993	Category 5 damage	Failure in the TR drive train
7.	Bell B205A-1 C-FJTF	1993	Damage to aircraft	Fractured 42^0 gearbox and high cycle, low-stress fatigue
8.	AS355F1 Ecureuil II G-SASU	1994	Damage to lower fin and left skid	Overheated aft pinion bearing
9.	Bell 206B Jetranger III C-FPQS	1994	Damage to helicopter	Aluminium aft short tail drive shaft had failed
10.	Super Puma G-BWMG	1998	Horizontal stabiliser detached	Fatigue crack, corrosion and micro pitting in tail drive shaft

Concept Explanation

The major components for our concept is shown in the block diagram along with its operation. The basic components of the proposed concept are,

- Engine Assembly
- DC Generator
- IC 7812
- Battery
- Sensor
- Micro Controller and
- BLDC Motor

Helicopters either uses reciprocating engines or turbine engines for their operation. But now-a-days turbine engines, especially turbo-shaft engines, are being used for its operation. This engine drives the main rotor through gearboxes and shaft links. These mechanical units transmits power to main rotor at a reduced proportion because main rotor are larger in structure which tends to catastrophe at higher speeds. Some helicopters incorporates pulley belt assembly for this purpose. This links usually has some shafts but they are quite long. This shaft length should be reduced as we do not require long shafts and pulley is mounted on it. Another pulley is mounted on the shaft of the generator. Both these pulleys are connected by a strong and long lasting belt made of rubber or composite. Instead of pulley belt assembly gear arrangement can also be used. The pulley attached to the engine is drive pulley whereas the pulley at the generator is driven pulley. Depending on the diameter of the pulley the RPM of the driven pulley is varied. Here we used a driven pulley with diameter less than that of the drive pulley.The generator output is connected to IC 7812. The purpose of this IC is to regulate constant 12v output. This output is stored in the battery. There are different types of batteries. But mostly lead acid batteries are used widely because of its huge advantages in fabrication. The battery assembly should be in such a way that there should be less discharging than charging.

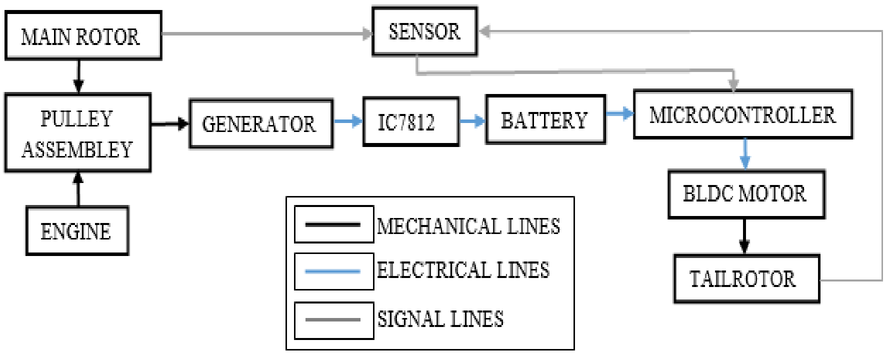

Figure 1: Block Diagram of the Concept

The voltage obtained from the battery is fed into the BLDC motor of the tail rotor to produce thrust. In order to produce enough thrust, so as to give effective anti-torque, the tail rotor should rotate in a proportion to the main rotor. To achieve this the tail motor RPM should be varied, which is done by a microcontroller. IR sensors fitted at main rotor gives input signal to the microcontroller which produces a desired voltage to drive the tail motor accordingly. The sensor gives different input signal whenever the main rotor RPM varies.

When the engine starts the shaft of the generator rotates due to rotation of pulleys. The shaft rotate in the gap between the magnetic poles of the generator inducing a flux voltage through the circuit. The obtained voltage from generator is regulated by IC 7812 to give constant 12v DC. This dc is stored in the battery which is then utilized to run the tail rotor's motor with the help of microcontroller for changing the RPM as per the requirements. Two batteries are used here, if one charges the other should discharge. There is a battery switch over which alters the work of battery.

Instead of just explaining the concept in words it is more effective if a prototype is fabricated. We have done a prototype of our concept for clarity and also as a proof.

Prototype Fabrication

In order to create a prototype of our ideology, certain components are required which is already stated. While choosing the components great care has to be taken because there are components with different ratings. Proper components should be chosen for fabricating the prototype.

A. Engine

Model engines are used in remote controlled aircrafts and finds major use in aero modelling. There are four basic types of engines for model airplanes- glow type, gas type, diesel type and electric. In our prototype we chose diesel engines because of its easy operation and reliability. These "diesels" run on a mixture of kerosene, ether and castor oil or vegetable oil. The carburetor supplies a mixture of fuel and air into the engine, with the proportions kept fairly constant and their total volume throttled to control the engine power. Compression is achieved by a "contra-piston," at the top of the cylinder, which can be adjusted by a screwed "T-bar". The swept volume of the engine remains the same, but as the volume of the combustion chamber is changed by adjusting the contra-piston, the compression ratio changes accordingly.

Figure 2: Model diesel engine

B. Engine Technical Details

Engine name	: FORA 1.5cc
Type	: Compression Ignition
RPM	: 22000
Engine power	: 0.67 HP
Fuel	: Diethyl ether (35%) +Castor oil (20%) +Kerosene (45%)
Weight	: 95gms
Diameter of piston cylinder	: 12.4mm
Stroke in the combustion chamber	: 12.4mm

C. Torque Calculation of Engine

Torque can be calculated for this model engine at different rpm values using the basic relations.

$$T = HP * 5252 / (rpm) \quad \text{in lb-ft}$$

This implies torque is inversely proportional to RPM.When there is no load acting on the engine, the engine rotates at its maximum prescribed rpm. But there will be some load acting on it so the maximum achievable rpm of the engine decreases.

Table 2. Main rotor rpm and torque

S.No.	RPM	Torque (lb-ft)*10^{-3}	Torque (Nm)*10^{-3}
1.	1500	0.328	0.445
2.	3000	0.164	0.222
3.	4500	0.109	0.148
4.	6000	0.082	0.111
5.	7500	0.065	0.089
6.	9000	0.054	0.074
7.	10500	0.046	0.063
8.	12000	0.041	0.055
9.	13500	0.036	0.049
10.	15000	0.032	0.044
11.	16000	0.030	0.041
12.	16500	0.029	0.040

D. Propeller

For the above engine suitable propeller should be used. So, we used a propeller of span 22cm of sizing 7”x4”. The propeller is 7” in diameter with 4” pitch. Propeller selection should be mainly based on pitch rather than diameter. The engine manufacturer has prescribed some alternate propellers also but we used the one which is most widely recommended.

E. Pulley Belt Assembly

The purpose of pulley belt assembly is to transmit power (mechanical) from engine to generator. Open belt drive is used for transmission.

F. Generator

Since the direction of rotation of the pulley is not changing the output from the generator is purely DC. The maximum voltage obtained from this generator is around 32v with ampere rating of 50mA to 60mA.

G. IC 7812

7812 is a famous IC which is being widely used in 12V voltage regulator circuits. It uses two capacitors, one on the input and second one on the output of 7812 in order to achieve constant voltage output and even these capacitors are optional to use. 7812 input voltage range is 14V to 35V.

H. Battery

Rechargeable lead-acid batteries are used for the prototype. There are two batteries and a battery switch over unit. Its purpose is to change the battery operation that is when one of the battery is driving tail rotor with full charge the other should undergo charging from generator.

I. Battery Details

Nominal Voltage : 12.0 v

Nominal Capacity : 1.2 Ah

Max. Charging current : 0.36 A

Max. Discharging current : 1.8 A

J. Brushless Dc Motor

The Brushless DC motor is a simple robust machine which has found application over a wide power and speed of ranges in different shapes and geometry. This motor is widely used in applications including appliances, automotive, aerospace, consumer, medical, automated industrial equipment and instrumentation. This motor is electrically commutated by power switches instead of brushes. Electric motors transform power from the electrical domain to the mechanical domain using magnetic interaction. In this motor, this magnetic interaction occurs between coils of wire on the stator, permanent magnets on the rotor (rotating part), and the steel structure of both.It operates at a maximum voltage of 12v with maximum rpm of 16000. Compared with a brushed DC motor or an induction motor, this motor has many advantages.

- Higher efficiency and reliability
- Lower acoustic noise
- Smaller and lighter
- Greater dynamic response
- Longer life

Because of the above advantages BLDC motor is used to drive tail rotor.

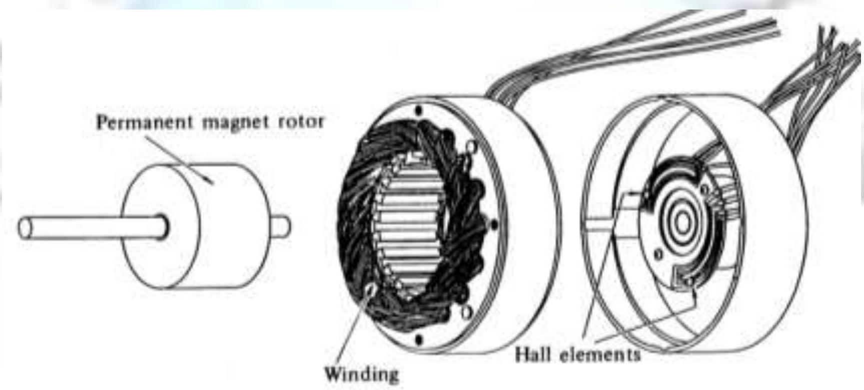

Figure 3: Disassembled view of a brushless dc motor

The table given below shows the voltage values corresponding to different rpm. These results are obtained from regulated power supply device in the lab.

Table 3: Tail motor rpm values and its corresponding voltage

S.No.	RPM	Voltage (V)
1.	1575	1
2.	3145	2
3.	4750	3
4.	6075	4

Microcontroller Based Voltage Control

The tail motor along with the tail rotor has to run at different rpms to achieve effective anti-torque. In order to achieve that the input voltage to the BLDC motor has to be varied according to the table 3. Automatic voltage control using microcontroller is the effective way of achieving it. The components includes two IR sensors, PIC IC F877A, resistors (both constant and variable), crystal oscillator, LM324 and LCD. IR sensors are fixed at main rotor and tail rotor. With input signal from IR sensor the PIC IC alters the output voltage according to the program fed in the microprocessor. PIC IC operates at 5v so there is IC 7805 voltage regulator. The purpose of crystal oscillator is to create pulse to the PIC IC. There is a feedback circuit which checks for proper voltage.

Tail rotor

Designing of tail rotor is the most critical part of fabrication because tail rotor's thrust should good enough to balance the torque of main rotor i.e., it should produce proper anti-torque.

Torque = Force * Perpendicular distance.

From helicopter aerodynamics [4]

$$Force = C_F * \rho_\infty * V_\infty^2 * S \text{ where } V_\infty = r\,\omega \text{ and } \omega = 2\pi N/60$$

Assuming thin airfoil theory, $C_F = 2\pi\alpha$

In order to sustain steady flight without rotation of helicopter body, torque should be equal to anti-torque. Using the above relations, tail rotor rpm values for different main rotor rpms has been found and tabulated below.

Table 4. Tail rotor rpm with respect to main rotor rpm

S.No	Main Rotor Rpm	Torque (Nm)	Tail Rotor Rpm
1.	1500	0.445	5341
2.	3000	0.222	3776
3.	4500	0.148	3083
4.	6000	0.111	2670
5.	7500	0.089	2388
6.	9000	0.074	2180
7.	10500	0.063	2018
8.	12000	0.055	1888
9.	13500	0.049	1780
10.	15000	0.044	1688

The figure given below is the exact prototype of our concept. Also it is checked for its correct operation.

Figure 4: Prototype of our concept with components labelled

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Result and Conclusion

From various analysis carried out fabrication of the prototype is complete. The design is verified by matching rpm of both main rotor and tail rotor according to our calculation. Over the last twenty five years, aviation industries are advancing to next generation technologies that mainly focuses on electrical and electronic systems. Both of these systems comes in miniature size compared to mechanical systems. Also they pose greater flexibility and reliability with less cost. Electrical systems can provide step-less speed variation over a wide range and can be stalled without damage. Its efficiency is greater when compared to its counterpart. Electrical systems have less moving parts and thus they are not nearly as subject to as much fatigue. Moving parts have inherent problems including binding, thermal fluctuations, cycle fatigue and other failure modes. With electronics, cycles are the main stay of design. Repeatability is much more accurate and tolerances can be higher. This electric driven tail rotor is less cost with reduction in weight and vibration.

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