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DESIGN OF CONTROL SYSTEM FOR ELECTRIC MOTOR OF TWO-STROKE HYBRID 800CC INTERNAL COMBUSTION ENGINE

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Abstract. *This work is part of an electrical and combustion propulsion workbench development. An 800CC two-stroke internal combustion motor, originally made for the BR800 Gurgel, was coupled in series to a specially built axial flux brushless DC electric motor. The objective of this work is the design of a drive circuit and the development of control strategy for the electric engine specific features. It is expected that the proposed drive and control system will be able to start-up the internal combustion motor. This paper shows the internal combustion engine, the electrical one and its features, a proposal for the workbench entire system with motor drive circuit and control strategy.*

Keywords: *Electric vehicle, hybrid engine, brushless DC motor, axial flux motor*

1. INTRODUCTION

Year after year the entire world discusses how to make the mondial car fleet more on electric cars, how to make cars more economics without emitting pollution gases directly. It is also known that this process is not going to be instantaneous, mostly because electric batteries energy density is lesser than the presented by fossil fuels. In the near future we could witness a massive popularization of hybrid cars.

At the automotive engineering laboratory of the University of Brasília at campus Gama, in 2017, a undergraduate project developed an electric axial flux motor and coupled it to an internal combustion engine (Botelho, Hildoglas, 2017), configuring a hybrid propulsion workbench. The purpose of this workbench is to permit studies of parallel hybrid systems that can be driven individually by a combustion machine or electric one. The Electric motor must be capable to start-up the system and the workbench also needs show the electromechanicals quantities involved in that process.

The electric motor is a brushless DC axial flux motor whose technology is more detailed in (Hyun,S. et al. 2017), (Nair, S. S et al.. 2011) and (Seo, J. et al .. 2010). These motors are more efficient than radial ones mostly because this topology can reduce the flux leakage and has better heat removal as seen in (Nair, S. S et al.. 2011). This kind of engine needs a magnetic field position feedback to be properly operated (Awari, P. et al.. 2017) and therefore, an array of Hall sensors was placed to implement this measure. This paper shows a description of the workbench's electric motor and exhibit a proposal of drive circuit and control strategy. The driver circuit must control with minimum losses a three phase inverter circuit implemented only by NMOS transistors and a special reference system (Toshiba Electronic Devices & Storage Corporation. 2018). The control of entire system, specially of the driver, is performed by the microcontroller ATmega2560 which receives the velocity reference, velocity feedback, Hall sensors signals and current measures. The entire system has a configuration like the ones shown in (Awari, P. et al.. 2017) and (Khergade, A. et al. 2016.). It is expected that at the end of this work, a viable low cost control system for the workbench will be obtained that will be ideal for tests and will serve as basis for a more robust system.

2. WORKBENCH SYSTEM

The workbench has both motors sharing the same shaft axis. The electric motor is driven by a 3 phase inverter powered by a 24V source and this device is controlled by the microcontroller ATmega328 platform. Between the inverter and microcontroller there is a driver circuit and there are also a sensor of the rotor's magnetic field (Hall sensor), rotation velocity and source current. The workbench project proposal is illustrated in Fig 1.

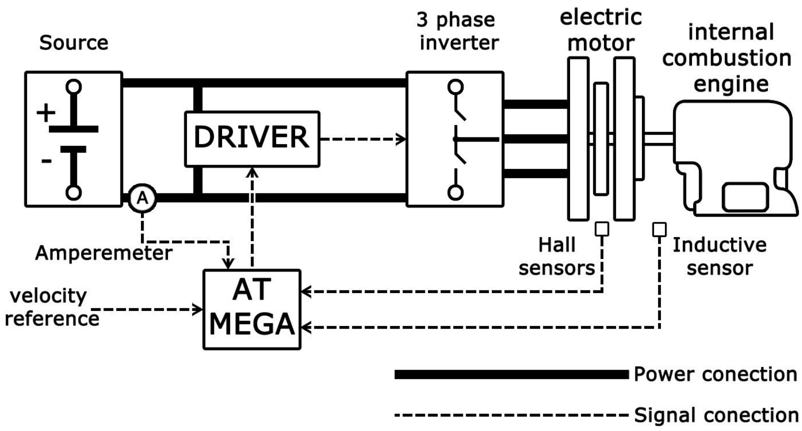


Figure 1. Workbench system block diagram.

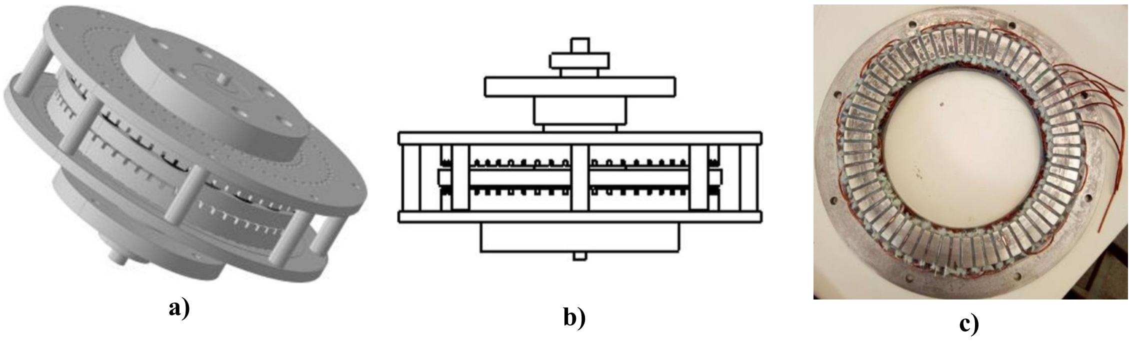
The combustion motor came from a Gurgel BR-800 vehicle and it is a 800CC motor, uses gasoline and has an electronic ignition, 2 horizontal opposite strokes, central valve command and water cooling. The Figure 2 shows the combustion motor from a catalog source and the motor fixed in the workbench.

a) b) c)

Figure 2. a) 800CC Motor. b)Workbench, combustion engine side. c)Workbench, electric engine side.

2.1 ELECTRIC MOTOR

The electric motor has a flat shape with 3 majors discs, 2 of them belongings to stator and 1 to rotor. Each stator disk has 3 wave windings.The rotor has 20 permanent magnets that are placed in way to align the magnetic field with axes which are parallel with the rotation axis, this scheme is known as axial flux motor. The Figure 3 shows three views of the electric motor and a rotor disk while the Fig. 4 shows the rotor and the stator.



a) **b)** **c)**

Figure 3. a) Electric motor in general view. b) Electric motor in lateral view. c) A stator disk in superior view.

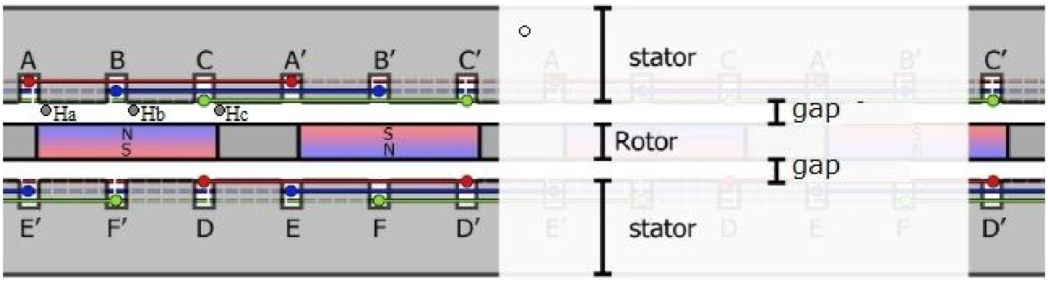


Figure 4. Detailed lateral view of rotor and stator.

The Figure 4 is a more detailed representation of the motor in a lateral view, it shows the stator disks, their windings, slots, rotor with magnets and the positions of Hall sensors, **Ha**, **Hb** and **Hc**. The wave windings must pass from an internal side to external side of the stator while the slots are the way between this sides. A slot has only one phase passing through it. The stators disks shown in Fig. 4 can be tagged as superior and inferior, the superior one has 3 phases, **A**,**B** and **C,** that must be connected with their pairs in the inferior stator, so that the phases has slots with same horizontal position and therefore the pairs are **A/E**, **B/F** and **C/D**. The phase coils was connected in star configuration, this connection can use two windings in a cycle with forward and backward activation, the Fig. 5 shows the inverter and coils connection.

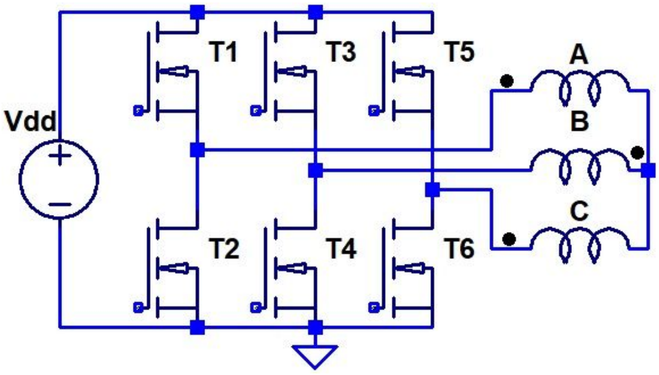


Figure 5. Inverter components and phase coils connection.

This electric motor can be driven as a brushless DC motor, this type of motor acts like a typical DC motor but instead of using a mechanical commutator, it uses a electronic commutation that can be performed by the constant measuring of the rotor magnetic field position, the Hall sensors are placed for this purpose.

Axial flux motors are more efficient than the radial ones because it can links the magnetic flux with less loss. Another efficiency feature is a higher managing of the stator coils, that gives more power density to the motor (Seo, J., et al .. 2010).

2.2 DESIGN OF ELECTRIC DRIVE CIRCUIT

The motor will be driven by 3-phase inverter circuit that can converts a continuous currents into a pulse sequence required by the electric motor. The inverter will use a 24V source, but it will be controlled by a microcontroller which uses 5V, so the driver must contain a power coupler stage to isolate the power circuit from the processing circuit.

An issue in the driver project is the simultaneous activation of two transistors in the same phase, that can leads to a short circuit that could damage the transistors. A logic circuit is introduced to avoid this problem and this logic circuit also receives a PWM input to modulates the gates signals. Therefore the inverter phase voltage can be modulated in order to control the motor speed.

The only switching device used is the NMOS transistor, it has advantage of being faster than bipolar technologies and it also is more common and cheap than other semiconductor switches.A trouble appears when a NMOS transistor is used in the high side of a inverter; the voltage in the transistor gate must be higher than inverter supply voltage in order to avoid the appearance of a voltage drop in transistor that can means more heat dissipation in the transistor and an unbalance in the inverter.

A gate driver is the circuit that delivers this higher voltage the transistor's gates and there are to many strategies to implement this. A popular approach consists in the usage of a capacitor with a floating voltage reference, known as bootstrapping capacitor, as shown in reference (Toshiba Electronic Devices & Storage Corporation. 2018) .

A commercial gate driver , IR2010, was chosen for the driver purposes, this IC can do the bootstrapping operation and has a power coupling between a logic stage and a power stage. Figure 6 shows the driver circuit for the phase A, and how it is controlled by signal **AH** and **AL** and how it controls the transistors **T1** and **T2**.

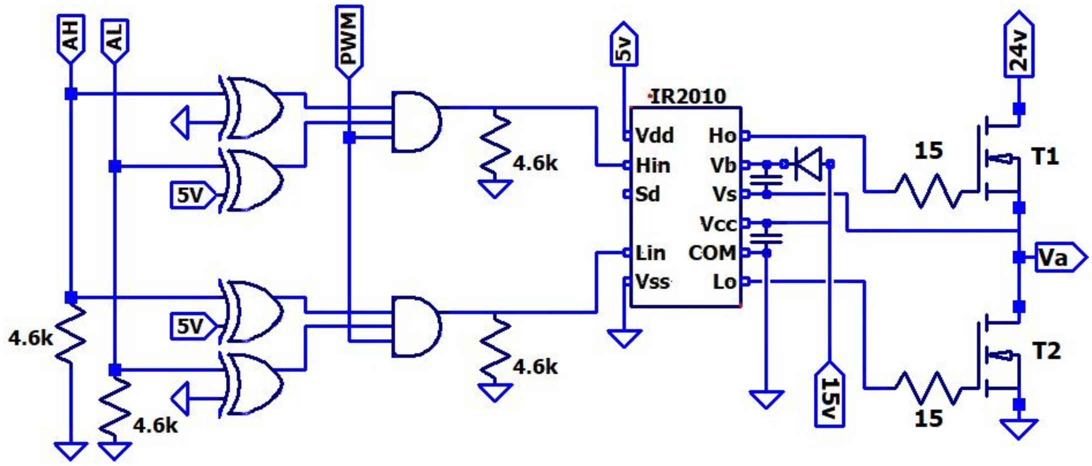


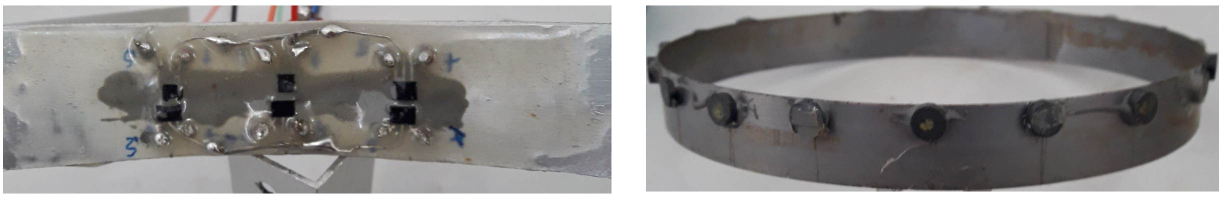
Figure 6. Phase A drive circuit.

3. CONTROL STRATEGY

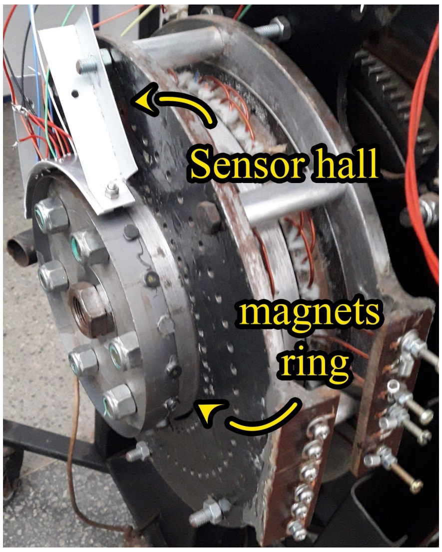
The inverter driver must use Hall sensors in order to be able to start-up a brushless motor and it is important to know if the coil is facing a north pole, a south pole or none pole.

Two issues appeared in the experimental setup. First, the sensor choosed, **A1101LUA-T**, can only detects the magnetic flux in one direction, to solve this, a pair of sensor were used to detect the rotor magnetic field variations in each phase, one of the sensors is placed in backwards position to detect magnetic flux in other direction.

Other problem is the fact that the motor wasn't built to receive the Hall sensor in the motor gap without disassemble the motor. A ring of magnets was built to represents the rotor magnets and this ring was placed at the engine external side of the engine. The Figure 7 shows the magnets ring, the Hall sensors and where they were placed.



a) **b)**



c)

Figure 7. a) Sensor array. b) Magnets ring. c) Electric motor with sensor Hall and magnets ring

The Hall sensor chosen has an inverted logic. When a magnetic field is detected, the sensor shows 0V and supply voltage when otherwise. The Table 1 shows which pair of coils must be turned on for each state of sensor Hall array.

state	Hall sensor logic value						Coil actuation	Transistor activation
	H_{AN}	H_{AS}	H_{BN}	H_{BS}	H_{CN}	H_{CS}		
1	0	1	1	1	1	1	$B\ A$	T1, T4
2	1	1	1	1	1	0	$A\ \overline{C}$	T1, T6
3	1	1	0	1	1	1	$\overline{C}\ \overline{B}$	T3, T6
4	1	0	1	1	1	1	$\overline{B}\ \overline{A}$	T3, T2
5	1	1	1	1	0	1	$\overline{A}\ C$	T5, T2
6	1	1	1	0	1	1	$C\ B$	T5, T4

Table 1. Hall sensor output and coil actuation for commutation states

There are other combinations for Hall signals but the one seen in Tab. 1 expresses the critical moments for coils commutation. In table a '$\overline{C}$' means that coil **C** is reversely fired.

4. CONCLUSION

The workbench was build by the joining of several subsystems that need to be properly coordinated for the workbench operation.

An important piece is the electric motor as it needs special attention in the windings connection and the motor also needs a rotor magnetic field monitoring system to comutates the motor coils. Construction problems appeared during the building of the rotor magnetic sensor system and this was resolved by placing a ring of magnets and a array of sensors at the in a external side of motor. This new arrangement made it possible to do the magnetic measurements.

The designed driver circuit can operates a NMOS transistors in both side of a inverter and it also has a logic protection scheme to prevents short circuit.

5. ACKNOWLEDGEMENTS

The autors acknowledge the work of Hildoglas Botelho on the mechanical assemby of the electic motor.

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