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Battery Operated Hydraulic Rig to Charge the Parking Brake Accumulator of Aircraft

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Abstract: This paper enables to collect all the relative information about parking brake system, changes of improving the current system. Parking brake is one of the important parts of an aircraft. The function of parking brake system is to slowly stop the aircraft safely at desire place on the ground. The purpose of using the hydraulic accumulator in parking brake system is to store the hydraulic liquid under system pressure. For proper brake operation the accumulator are charged to the pressure of 207 bar. Earlier the manual hand pumping is used to charge the accumulator which is time consuming not so accurate pressure is filled in an accumulator to overcome such problems the battery operated hydraulic rig is developed. This is capable to charge the 50 parking brake accumulators of aircraft once the battery is fully charged. Since it is battery operated so no continuous 3-phase supply is required in the field. Systems will supplies hydraulic pressure to the aircraft parking brake accumulator. The DC motor is operated by a rechargeable LiFePo4 battery, it acts as a source for the motor/pump unit. The pressure switch is used to monitor the pressure in the accumulator. Inline filter is used to filter the oil of the rating 3 micron rating absolute. The LiFePO4 battery charge indication circuit is developed. Hydraulic rig build the 207 bar pressure in the accumulator in an interval of 20sec. The discharge voltage characteristic of LiFePO4 battery and temperature characteristics of pump and dc motor are studied.
Keywords: LiFePo4 battery, DC motor, Pressure switch, check valve, MIL-H-5606 oil, Inline Filter.

INTRODUCTION

In early day aircraft have no brake system to slow or stop the aircraft on the ground. Instead, they slow down the speed on the landing airfield surface, and the friction developed by the tail skid to decrease speed during ground operation. Brake system was proposed after the world war-I as the complexity and speed of aircraft increased. All modern aircraft are consisting brake system. The proper function of brake system is to stop the airplane safely on the ground. The brake slows down the aircraft and stops it in a reasonable amount of time. The aircraft main wheel is equipped with brake system. The basic function of brake is to convert kinetic of movement into heat energy by creating the friction on the ground surface. In the normal brake system, hydraulic or mechanical linkages to the rudder pedals are controlled by the pilot. The purpose of using the using the hydraulic accumulator in parking brake system is utilized to collect the hydraulic liquid under system pressure. Accumulator area is divided into two parts and the area is isolated by a bladder. One section contains a gas (air or nitrogen) and the reaming half contains the working liquid. The gas is pressurized to reduce the working pressure to half. Developed along this way the gas will act as a damping device and levels out pressure variation and it likewise serves as back up pressure during the pump failure. The brake accumulator is placed at the aft fairing in airplane. The volume of brake collector is 25 cubic inch. The accumulator is intended to provide 6 emergency brake applications or parking brake pressure for roughly 48 hours. The parking utilizes hydraulic pressure supplied by the right hydraulic system. The nominal 3000 psi (206.85bar) pressure is provided by the accumulator placed on the right engine accessory gearbox. Now a day's high-pressure accumulator system is developed for different applications. Nitrogen gas is used rather of air because it produces a less corrosion effect.

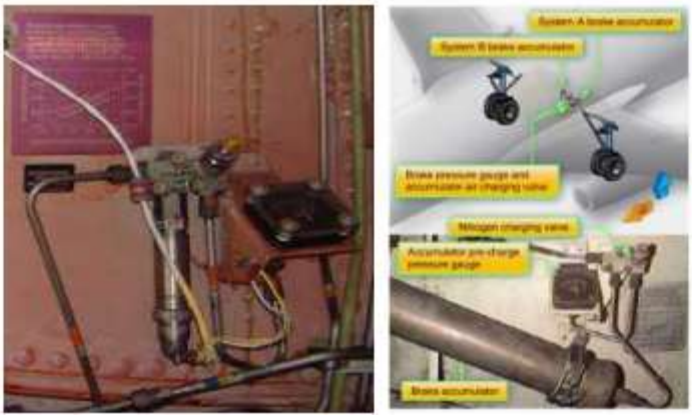

Fig- 1: Aircraft parking brake accumulator

Hydraulic operated aircraft accumulator

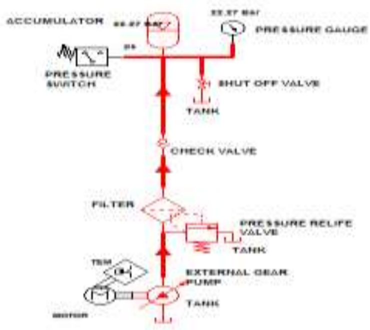

Fig-2: Hydraulic operated aircraft accumulator

In this mechanism, pressurized oil is supplied to the accumulator system through a check valve. The oil gets filtered before it enters into the accumulator. Filters are used for filtering the pressurized oil. In this system, the check valve is used to flow the oil in a single direction. It blocks the oil when it flows in the backward direction. The pressure switch is connected inline to the accumulator to control the system pressure to required value. Accumulator stores the hydraulic pressure in the presence of pre-charged nitrogen gas. The accumulator continuously deposits the hydraulic pressure until the circuit is a break with the pressure switch. The system contains the pressure gauge which indicates the in exist in the hydraulic accumulator. It consists of a temperature sensor which monitors the temperature of the motor if the temperature of the motor exceeds the desired value the motor automatically turn off.

Project Objectives

1) Developing the battery operated hydraulic system to charge the 20 parking brake accumulators in 20 seconds each
2) The system should build 207 bar pressure in the accumulator in 20 seconds. Once the accumulator pressure reaches the 207 bar then the system should automatically turn off.
3) During the process if the temperature of the motor reached 120 ^{0}C then the motor should automatically turn off.
4) The system should filter the MIL H 5606 oil with a rating of 3-micron absolute.
5) The design of 24V 20Ah battery charge indication circuit to indicate 100%, 75%, 50% and 25%. Once the battery reach below 50% then it automatically gives the buzzer sound.
6) Overall system weight should not be more than 70kg.

LITERATURE SURVEY

Paulo G. Pereirinha *et al.,* [1] examined the Characteristic of lithium iron phosphate battery with the test setup in an electrical vehicle. Finally, conclude that the performance characteristic of LiFePO4 battery for an electrical vehicle is good as compare to other battery pack.

R.P. Middendorf and D.E. Keyser [2] designed the reverse modeling brake system, explained the functions of Hydraulic system in the parking brake and emergency system and also explained the component required in the conventional hydraulic system. Explain the pre-requirements of the brake system, design considerations, and selection of components for the brake system.

Abdulgaffar doddamani and Charukeerthi A, [3] discussed the various components in the field of electro-hydraulic proportional and control technologies and provide the information about the advanced hydraulic system.

DarkoLoVrec *et al* [4] created checking strategies for an online condition which is appropriate for hydraulic components, entire drives of hydrodynamics and liquid of pressure driven.

METHODOLOGY AND COMPONENTS

Battery operated hydraulic consisting of the hydraulic and electrical component which is installed in a single unit. The hydraulic rig is meant for charging accumulator using battery operated motor/pump unit. The working methodology of the system is explained in below topics.

Block Diagram:

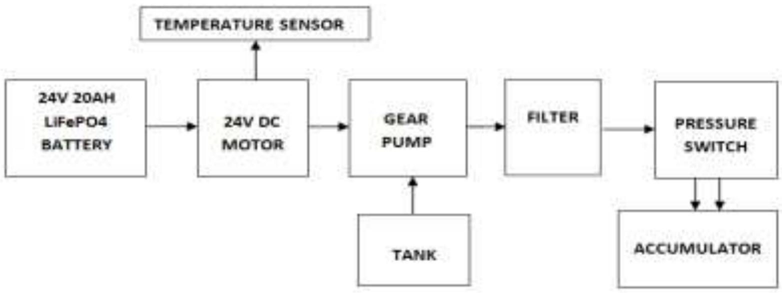

Fig-3: Block diagram of the system

Hydraulic Circuit Diagram

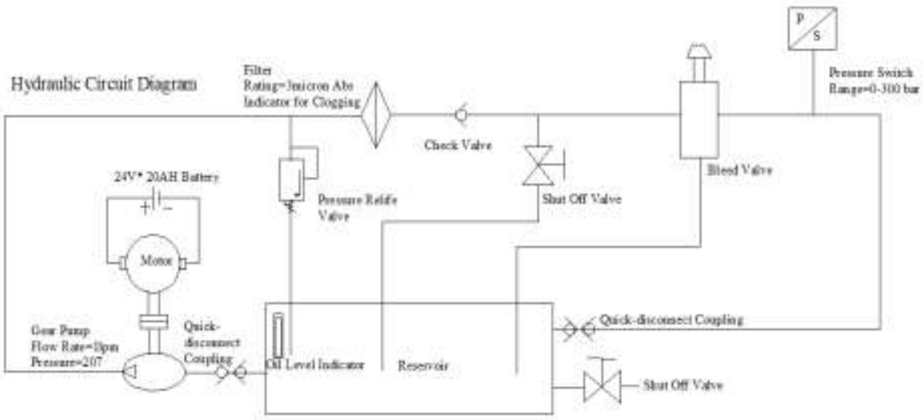

Fig-4: Hydraulic Circuit Diagram

The hydraulic test rig is meant for charging accumulator using the battery operated pump. The fluid from a reservoir is drawn by a pump and the pressurized fluid is supplied to the accumulator. It consists of a gear pump with rated flow of about 1 lpm and is driven by a DC electrical motor of 800W. The DC motor is operated by a rechargeable battery of LiFePo4, 24V x 20Ah. The pump outlet is connected to pressure line filter with a micron rating of 3 micrometers absolute and bleed valve and handle valve through a check valve. The return line of bleed valve is a transparent hose for visual auditing of air entrapment. A pressure switch with a digital indicator is used to calculate the line pressure and accumulator housing pressure and its analog output is used to switch off the motor when accumulator get charged to required pressure of 207bar. The hydraulic rig has reservoir made out of stainless steel with a capacity of 5 liters and it is filled with MIL-H-5606 oil. The pump inlet hose and test rig outlet hose are attached to the tank using QDC. To assure there is no air entrapment in the line and also to required oil cleanliness level of NAS class of 4 before charging the accumulator, the pump is run and the oil is circulated with the tank. The bleed valve is operated and visually checked for air entrapment and oil sample is collected from minimess coupling to verify the oil cleanliness level. All the elements are mounted on a rig with 4 wheels and the elements are housed inside an appropriate case. The diameter of wheels is 5’’ made from PU or hard rubber molded over cast iron or stainless steel core with bearings. These wheels are shock absorbing type with low noise level. The hydraulic rig consists the collapsible handle. The material used shall be of stainless steel sheet of fourteen gauge minimum with brushed finish and structural members are high-quality CRES steel. The rig consisting lifting handles for lifting purpose. For charging the accumulator the pump inlet and test rig outlet hose are disengaged from the reservoir and they are connected to the tank and accumulators respectively using quick disconnect coupling (QDC). Above figure shows the recommended hydraulic circuit for the hydraulic rig.

Main components of the battery operated hydraulic rig

Battery operated hydraulic rig is built with several indigenous parts packed into a single unit.

LiFePo4 Battery

The battery used in proposed hydraulic rig is 24V 20Ah lithium iron phosphate battery LiFePo4.

Fig-5: LiFePo4 Battery

Table 1: Specification of LiFePo4 battery

SI No	ITEM	SPECIFICATION
1	Nominal Capacity	20Ah
2	Nominal voltage	24V
3	Max. discharge current	40A
4	Charging Time	4H
5	Operating Temperature	Charge: 0 to 55°C, Discharge: -30 to 55°C
6	Pack Weigh	About 6Kg
7	Size	62mm X 168mm X 250mm

LiFePo4 Battery Charger

The 24v 20Ah LiFePo4 is charged using the 29.2V * 5Amp LIFePo4 Battery charger. The charger is the voltage limiting device. It provides the accurate charging control, fixed status monitoring and effective battery protection.it charges the battery at a faster rate and 100% standalone protection and high-reliability operation.

Fig-6: LiFePo4 Battery Charger

DC Motor

Rating of the DC motor is 24v, 800w, 4000rpm. It consisting of 2 input terminals i.e. positive and negative terminals. The positive terminal is connected to battery positive terminal and a negative terminal connected to battery negative terminal. The output of the dc motor is mechanical work i.e. shaft rotation it is connected to pump inlet.

Fig-7: DC Motor

Gear Pump

Gear pump consisting mesh of gears to pump the oil by displacement. The gear pump used in this system is one direction rotation i.e. in the anticlockwise direction. The rating of the gear pump is 1lpm, displacement is 0.25 cc/rev, flow rate at 1500 rpm (l/min) is 0.37 intermittent maximum pressure is 190 bar and peak maximum pressure(maximum 2 seconds) is 230 bar.

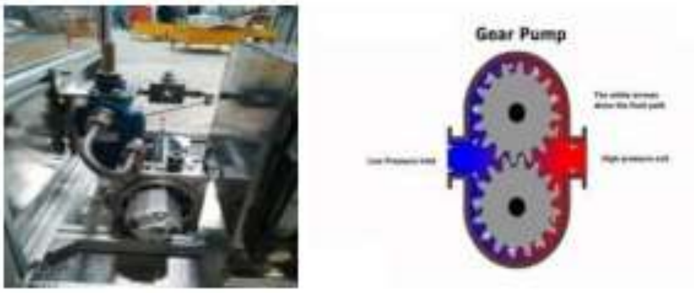

Fig-8: Gear Pump

Oil Tank

The hydraulic rig has reservoir made up of stainless steel having the capacity of 5 liters and it is filled with MIL-H-5606 OIL. Steel tank is well finished and is capable of the operating temperature range of -15°C to +80°C.

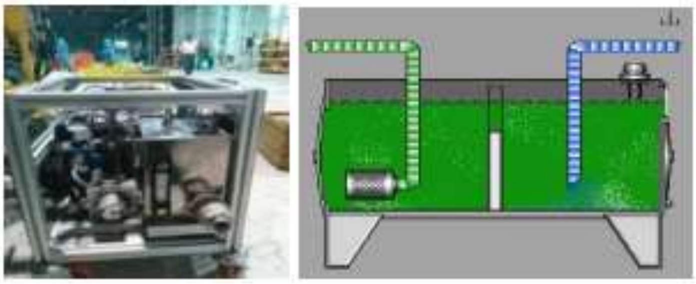

Fig-9: Oil Tank

Temperature Sensor

It is attached to the motor, whenever the temperature of DC motor reached the 120^{o}C then it gets activated. The output of temperature sensor is connected to normally closed (NC) contactor. Whenever the temperature of motor reached 120^{o}C then it sends the signal to NC contactor, NC contactor converted into the NO contactor due to this no supply goes to the motor from the battery, and motor gets disconnected.

Inline Filter

Filters used in this hydraulic rig to separate the solid material from the lubricating oil. The pump outlet is connected to pressure line filter with a micron rating of 3µm absolute. And it filters the oil and removes the moisture contains in the oil.

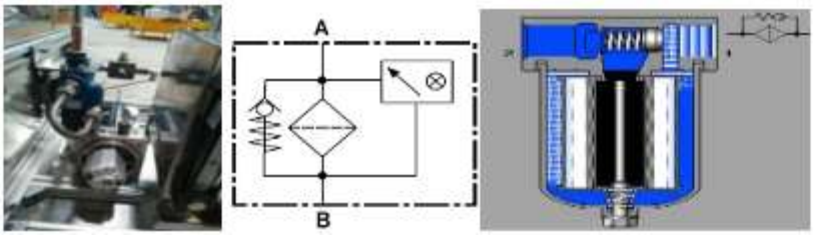

Fig-10: Inline Filter with Mechanical Indication

Some of the points related to inline filter are

1. Nominal pressure 250 bar.
2. Operating temperature -10°C to 100°C.
3. Inline filter installation
4. Filter the very minute particles and high dirt holding capacity.
5. Different, voluntary electronic switching elements, modular design.

Oil Level Gauge

It is used to measure and indicate the oil level of 5-liter tank which is used in this system. The temperature limit of this indicator is 80°C. It is fixed outside the tank unit with the two mounting holes. It consisting the unbreakable clear glass which gives high visibility.

Pressure switch

It is a compact electronic pressure switch with integrated analog output. A pressure transducer with a digital indicator is used to indicate the line pressure and accumulator housing pressure. It converts measured value into electrical signal variables in the hydraulic system. Its analog output is used to switch off the motor when accumulator is charged to required pressure of 207 bars.

Fig-11: Pressure Switch

Check Valve

A ball check valve is a one direction flow control valve which consisting of the ball is made up of metal having spherical in nature with spring loaded. It moves the oil in the forward direction and stops the flow of oil in the reverse direction due to which pressure build in the accumulator. These are small in size and the working operation is shown in the Figure 12.

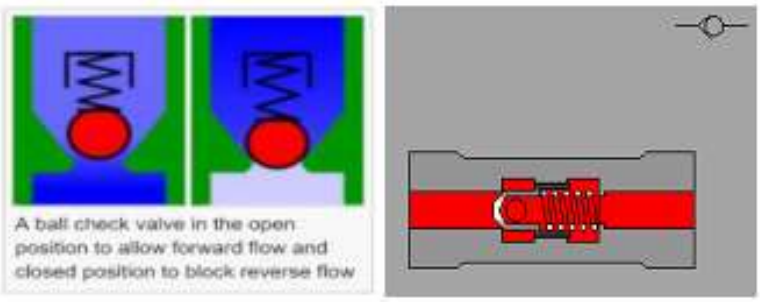

Fig- 12: Check valve

Pressure Gauge

It is a pressure measuring and indication instrument which measure the high dynamic pressure of accumulator . The outer part of the gauge is made up of stainless steel.The measuring scale limit of the pressure gauge is four hundred bar pressure.the pressure gauge is installed inline to the accumulator to measure the accumulator pressure.

Fig-13: Pressure gauge

Suction Hose

Suction hose used in this system is highly synthetic rubber in nature. It is used to connect between hydraulic rig and aircraft parking brake accumulator. The length of the hose is 3 meters long and 0.65-inch diameter. The hose used in the hydraulic rig is flexible in nature and high temperature withstanding capacity around -40^{o}C to +120^{o}C. it sustains high hydraulic pressure.

Fig-14: Suction hose

Flow Chart of the System:

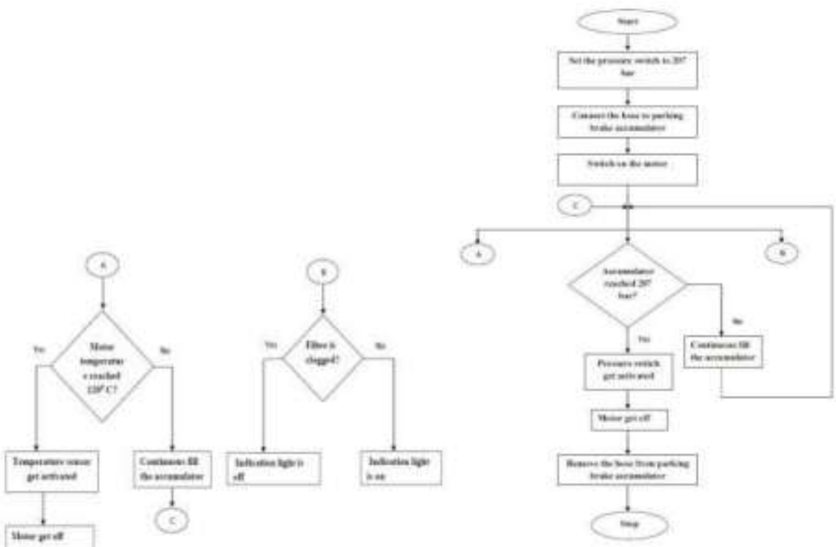

Fig-15: Flow Chart of the system

Battery Charge Indication Circuit

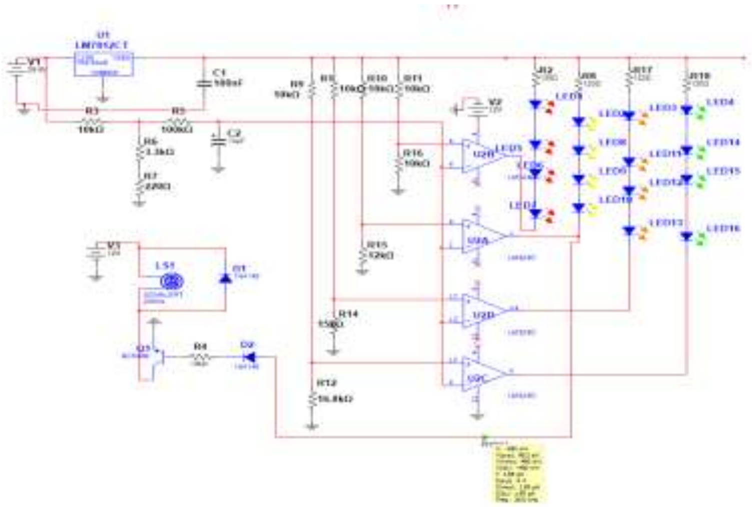

Fig-16: Battery Charge Indication Circuit

This battery charge indication circuit consisting the 4 set of LED's that light up progressively as the voltage increases. Design circuit mainly consisting of voltage comparator integrated circuit(IC) LM324, is used to compare the battery voltage with the reference voltage.7812 is the voltage regulator which regulate the 24v battery voltage to 12v. R16, R11 are the voltage divider resistor which divides the reference voltage 11.8v to 5.9v this value is compared with battery divider voltage. When battery divider voltage is greater than reference voltage than 25% LED's are glow. R3, R6 and R7 are the voltage divider resistor which divides the battery voltage by the factor of 4. R10, R15 are the second set of voltage divider resistor which divides the reference voltage 11.8v to 6.43v. R1, R14 are the third set of voltage divider resistor which divides the reference voltage 11.8v to 7.08v. Similarly R9, R1 divides the reference voltage 11.8v to 7.4v. The battery divider voltage and a reference voltage are compared in the LM324 IC. If the battery divider voltage is higher than reference voltage then a corresponding series set of LEDs glow. The comparator sections have open collector output that simply functions as a switch to operate the LED's. The LED's are biased to operate at one milli-ampere which is relatively bright in nature and greater efficiency. Capacitor C2 act as a bypass capacitor. When battery voltage smaller than the 50%, current flow to the n-p-n transistor through the D2 diode. Diode D2 get active only when the positive current pass through it. A small current pass through the base of the npn transistor the current get amplified in the npn transistor to provide greater emitter and collector current. When a greater voltage is measured across the emitter of an n-p-n transistor to its base (i.e. at the point when the base is relatively greater than emitter current) also greater potential difference measured from the base to collector. Buzzer is on when transistor gets activated. Switch button is provided to stop the buzzer sound.

DC Motor Control Wiring Diagram

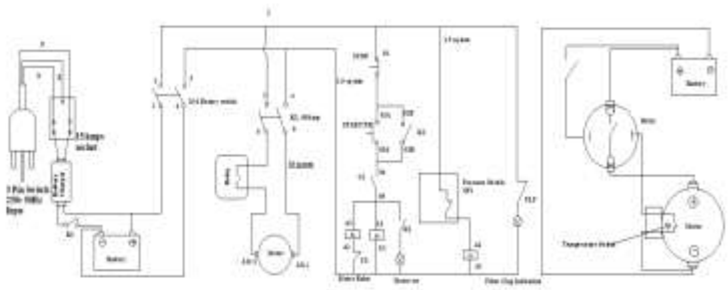

Fig-17: DC Motor Control Wiring Diagram

The hydraulic rig consisting ON/OFF switch to monitor the battery operated pump. The control circuit diagram consisting of 15 amperes socket the input for the socket is 230V supply. And the output is connected to the battery charger of the rating 230V, 5A and the output of the battery charger is connected to the battery through a contactor k1. The battery gets charged only during the motor is off condition. The output of the battery is connected to the motor through two switches (rotary switch and contactor switch of the rating 50 amperes) and one relay of the rating 24V, 150amperes through the 16sq.mm, cable. Whenever the start button is applied the supply goes to the pressure switch which is initially normally closed (NC), the coil C1 get energized due to which k1 contactor gets activated, motor gets started through the relay. When the pressure of accumulator reached 207bar then pressure switch becomes normally open (NO), the coil C1 get off and the k1contactor gets deactivated and motor gets to switch off automatically. During the process if the temperature of the motor reached 120^0C then temperature switch get normally open then Ts became an open circuit , no supply goes to the relay, relay gets disconnected due to which no supply goes to a motor so motor gets switched off. Filter clog indicator (lamp) is provided on the panel. During healthy condition lamp is on condition which indicated the filter is in healthy condition when the filter clogged then indication lamp get off which indicate the non-healthy condition.

Battery related theoretical calculations

Battery Rating: 24V, 20Ah
Motor Rating: 800W, 24V, 4000RPM
Current drain by motor from battery(I_m) = Power in watt (W)/ Voltage rating of motor (V)
I_m =800/24=33.33A
Battery capacity (AH) = [(Motor rating* No of hours)/battery voltage]
20AH = [(800*No of hours)/24]
Number of hours motor run's once the battery fully charged= 20*24/800 =0.6hrs
No of minutes motor run's once the battery fully charged=36 Minutes
Battery Charger rating=24V, 5A
Time taken to charge the battery in hours = battery ampere-hours (AH)/current rating of the charger (I)
=20/5 =4hrs

Practical calculation

During operating time the current drain by electrical system from battery (I_S) = 40A
Therefore, Number Of hours motor run = battery capacity (AH)/Current drain by the system (I_S)
=20/40
=0.5hrs

Hydraulic Calculation

For selecting the pump flow rate at operating pressure of 207 bar the following calculation are carried out. Also calculated the torque drained by pump in Nm and power absorbed by the pump in KW.

Given: Drive shaft in rpm (n) =4000. Mechanical Efficiency (η_{mech}) =0.87.
Volumetric Efficiency (η_{vol}) =0.95
Pump Displacement (cm^3/rev) = 0.25.
Operating Pressure (bar) =207
Flow rate from pump Q [l\min] = [Pump Displacement* Drive shaft (n)* η_{vol}*10^{-3}]
= 0.25*4000*0.95*10^{-3}
=0.95
Torque absorbed by pump T [Nm] = [(Pump Displacement*operating pressure)/ (20π*η_{mech})]
=[(0.25*207)/ (20*3.142*0.87)]
=0.9471
η_{tot}= η_{mech}* η_{vol}
=0.95*0.87
=0.8265
Power absorbed by pump N [KW] = 2π*10-3*Torque absorbed by pump T [Nm]* Drive shaft in rpm (n)/60
= Q [l\min]* operating pressure [bar]/600* η_{tot}
= 0.95*207/600*0.8265
=0.3965

TESTING AND RESULTS

The final testing of battery operated hydraulic rig for charging parking brake accumulator of aircraft is carried at Bosch Rexroth limited, peenya second stage, Bangalore. Readings obtained during final testing are tabulated in the Table 2

Fig-18: Final testing of battery operated rig

Table 2: Final testing Readings of battery operated hydraulic rig

No of Cycles	Test run time	Battery voltage In volts	Time in secWith time gap of 3min	Motor Temperature in ^{0}C	Pump Temperature in ^{0}C	Pressure in bar
1	2.28 pm	28.4	20	35	33	0-207
2	2.31 pm	27.2	20	36	33	0-207
3	2.34 pm	26.8	20	37	33.234	0-207
4	2.37 pm	26.6	20	39	34	20-207
5	2.40 pm	26.6	20	40	34.6	20-207
6	2.43 pm	26.6	20	40	34.8	10-207
7	2.46 pm	26.6	20	40.6	34.6	30-207
8	2.49 pm	26.6	17	41.8	34.6	30-207
9	2.52 pm	26.5	20	42.8	35	40-207
10	2.55 pm	26.5	22	43	35.6	40-207
11	2.58 pm	26.5	20	44.2	35.8	40-207
12	3.01 pm	26.5	20	45.6	35.8	40-207
13	3.04 pm	26.5	20	46.6	36.2	40-207
14	3.07 pm	26.5	21	46.6	36	40-207
15	3.10 pm	26.5	20	46.8	36.4	40-207
16	3.13 pm	26.5	21	47.6	36.8	40-207
17	3.16 pm	26.5	21	48	37	40-207
18	3.19 pm	26.5	20	48.4	37.2	40-207
19	3.22 pm	26.5	21	48.8	37	40-207
20	3.25 pm	26.5	20	49	37.5	40-207
21	3.28 pm	26.5	20	49	38.2	0-207
22	3.31 pm	26.5	20	49.6	38.4	40-207
23	3.34 pm	26.5	20	50	38.5	40-207
24	3.37 pm	26.5	20	50	38.4	40-207
25	3.40 pm	26.4	21	50	38.8	40-207
26	3.43 pm	26.4	21	50.6	38.4	40-207
27	3.46 pm	26.4	21	50.6	38.6	40-207
28	3.49 pm	26.4	21	50.8	37.6	40-207
29	3.52 pm	26.3	22	51	38.6	40-207
30	3.55 pm	26.3	20	51.4	38	40-207
31	3.58 pm	26.3	20	51.8	38.4	40-207
32	4.01 pm	26.3	20	52	38	21-207
33	4.04 pm	26.3	21	52	38.2	40-207
34	4.07 pm	26.3	21	52.2	38.8	40-207
35	4.10 pm	26.3	20	52.2	38.8	40-207
36	4.13 pm	26.2	20	52.4	38.6	40-207
37	4.16 pm	26.2	20	52.5	38.6	40-207
38	4.19 pm	26.2	21	51.8	38.4	40-207
39	4.22 pm	26.2	21	51.8	38.4	40-207
40	4.25 pm	26.2	21	52.6	38.4	40-207
41	4.28 pm	26.2	21	52.6	38.4	40-207
42	4.31 pm	26.2	20	52.6	39	20-207
43	4.37 pm	26.2	20	52.8	39.3	20-207
44	4.39(2min gap)	26.2	21	52.8	39.6	40-207
45	4.41 pm	26.2	20	52.9	38.8	40-207
46	4.43 pm	26.2	20	52.9	38.6	40-207
47	4.45 pm	26.1	20	53	38.2	40-207
48	4.47 pm	26.1	20	53.4	38.8	40-207
49	4.49 pm	26.1	21	54.4	39.4	40-207
50	4.51 pm	26.1	20	54.8	39.4	20-207

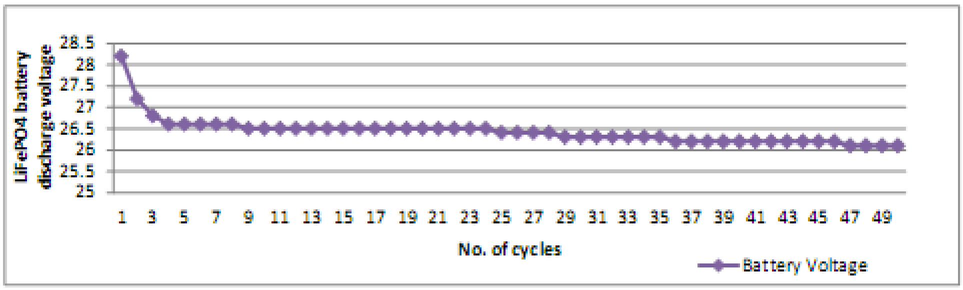

Fig-19: LiFePO4 battery discharge voltage characteristic

The graph (Figure 19) represents discharge voltage characteristics of LiFePO4 battery at different operating cycle. Initially, the battery voltage is 28.4V after the end of 50th cycle voltage is 26.1V. Starting 4 cycles the voltage decrease gradually after it remains constant.

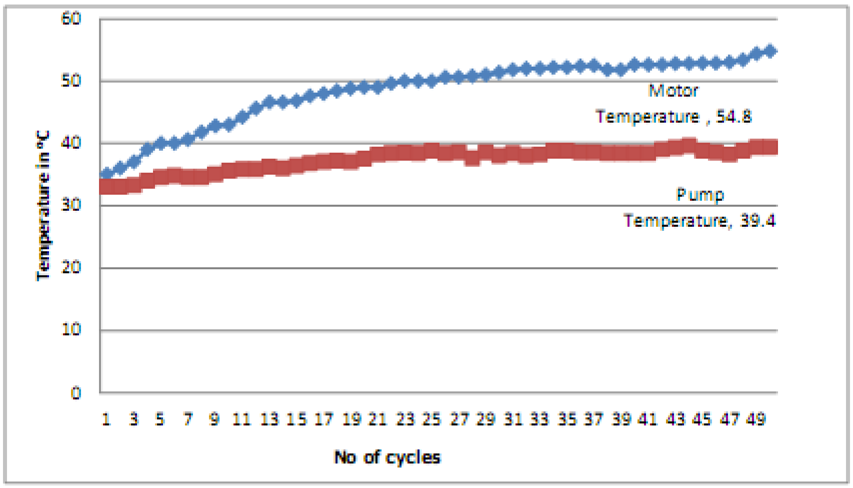

Fig-20: Temperature characteristics of dc motor and pump

The graph (Figure 20) gives the temperature characteristics of motor and external gear pump at different operating cycle. The temperature of motor and pump increases continuously for all the operating cycle. But after the end of 50cycles temperature of the motor is within the ambient temperature so there is no effect on the performance of the motor.

CONCLUSION

The battery operated hydraulic rig to charge the parking brake accumulator of aircraft is successfully developed and tested in the Bosch Rexroth India Limited. The proposed system is battery operated hydraulic rig so no continuous three-phase supply is required almost 50 aircraft parking brake accumulator are charged once the battery is fully charged. 24V LiFePO4 battery charge indication circuit was designed and tested. The proposed hydraulic rig is compact in size and easy to carry from one aircraft to another aircraft. Electrical motor/pump unit build 207bar pressure in aircraft brake accumulator system in 20 seconds. It is automatically turn off once the accumulator is fully charged. The motor/pump runs periodically by keeping the standby accumulator charged so that the system is ready to use. The rig is equipped with the inline filter to ensure the oil cleanliness. The filtration capacity of the filter is 3microns absolute. Practically, the filter element collects the dirt which is automatically indicated in the control panel.

Future scope

- Installing the hydraulic rig with a solar panel: Hydraulic rig is operated by 24v battery, which can be charge by connecting 24V solar panel.
- The system can be made fully automated: Moving the rig automatically from one aircraft to another with the help of artificial intelligence system.

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