OVERVIEW OF MECHANICAL CIRCULAORY DEVICES WITH DIFFERENT MOTORS

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Abstract*—Mechanical circulatory support (MCS) plays life saving role in patients with heart diseases and pulmonary diseases. Total artificial hearts (TAHs) and ventricular assist devices (VADs) are considered as MCS devices. This paper gives the brief description about MCS devices. Starting developed MCS devices were made as reciprocating type, but newer developments are with rotary type devices. They replaced the reciprocating devices with smaller and simpler structure. This paper also explains about motors were seen already in MCS devices. Percutaneous cables and Trasacutaneous energy transmission (TET) is used in implantable circulatory devices. Detailed Information about energy transmission system in MCS devices are given in this paper.*

Keywords*— Total Artifical Heart, Ventricular Assist Devices, Different motors in MCS devices, TET sysyem.*

I. INTRODUCTION

LVAD use is promising, will continue to grow, and has become standard therapy for advanced heart failure as a bridge to recovery, as destination therapy, Mechanical circulatory support helps to keep their heart pumping enough blood. Heart disappointment is an expansive range of illness and extents from patients who do well for a long time with oral treatment to patients who require cardiovascular transplantation.[1] For patients with final stage heart disappointment, various alternatives are presently accessible, including in trope basis(both inpatient and outpatient), cardiovascular transplantation, and long term mechanical circulatory help (MCS). Heart transplantation remains the complete treatment for patients with final stage heart disappointment patients; in any case, attributable to restricted benefactor organ accessibility and long hold up times, continuous stream left ventricular assisting devices (CF-LVADs) have turned out to be standard treatment for the administration of final stage heart disappointment both for patients who will inevitably get a transplant (extension to transplantation) and as a possibility for the individuals who may not fit for transplant but rather meet all requirements for long term MCS (goal treatment). [2] The idea of utilizing MCS started around 90 years prior when Dr Michael DeBakey, at that point an understudy at Tulane University, built up the roller pump.[3]. This critical leap forward in the end considered the lung bypass and advancement of the primary heart. The primary pulsatile LVAD HeartMate XVE (Thoratec Corp.) was affirmed in 1994 as an extension to heart transplantation and in 2003 was endorsed for goal treatment, as appeared in Figure 1.[4][5]. The step towards VADs started in 1932 and the steps towards a total artificial hearts started in 1957. The frequency and predominance of heart disappointment have consistently expanded in the United States for as long as quite a while. As of now, an expected 5.7 million Americans >20 years old have heart disappointment. Projections demonstrate that heart disappointment predominance will keep on increasing amid the following quite a long while, with evaluations of more than 8 million individuals being influenced by 2030. [6]. and the statistics are saying that there may be a chance of increase in the heart diseases mortality rate is about 120% to 130% in men and 110% to 120% in women.[7]. The above are the reasons behind MCS support developments.

The starting stage developments in MCS are attempted to reproduce the typical pulsatile stream of the heart, yet they were noisy and substantial, required an expansive percutaneous lead, and were not sturdy. Then they moved to continuous flow devices by eliminating the disadvantages in earlier stage pulsatile devices. Earlier stage devices were made with pusher plate mechanism and those are reciprocating type devices. The life span of first/earlier generation devices is limited to two years only [8]. Second generation continuous flow devices are rotary pump mechanisms, developments were seen to rotary pump mechanism from reciprocating type was only to decrease to size and complex structure nature. By design, CF pumps provide continuous forward flow as well as unloading. Therefore, patients supported with a CF pump will have a diminished pulse pressure and sometimes no pulse at all [9]. Even though they achieved smaller size requirements but failed in introducing the pulsatility. Left ventricular recuperation rate gets slower with the diminished pulsatility and Diminished nature of pulsatility increases the pressure gradients on the aortic valve. Complexities with mechanical bearings in continuous flow devices are eliminated in third generation devices by introducing magnetic levitation bearings.

Amid the previous quite a long while, these devices have moved from pulsatile stream to a nonstop stream innovation. The advantages of persistent stream devices incorporate being one-seventh the span of the first devices, one-quarter the weight, and calmer with a littler percutaneous lead and enhanced sturdiness. Presently, [1]the most well-known LVADs being embedded in the United States are second and newer generation devices, the HeartMate II (Thoratec Corp., St. Jude Medical) and the HeartWare HVAD (HeartWare International, Inc.). A fresher third generation pump (HeartMate III; Thoratec Corp., St. Jude Medical) intended to make a fake heartbeat is right now under scrutiny in the United States. Figure. 3. [10] presented fig. 2. Evolution MCS devices.

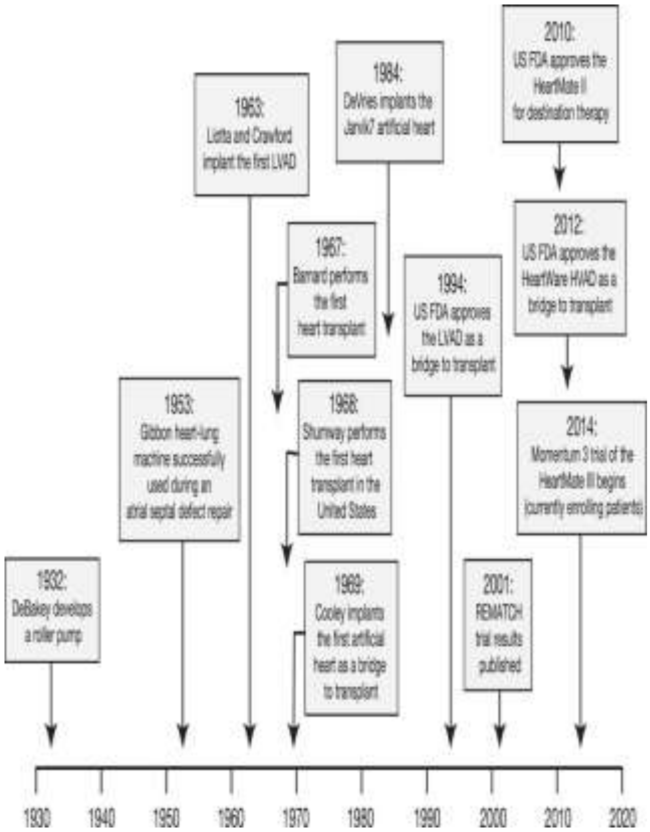

Fig.1. Developments of VADs and TAHs.

Fig.1 is about Developments of VADs and TAHs. Main components in MCS devices are viz., controller, Pump, Motor etc. motor is associated to mechanical pump. Mechanical energy of motor-pump assembly helps to pump blood accordingly.

Fig.2. Mechanical circulatory devices [10]

Device	FDA-Approved Indications	Pump Design and Speed Range	Pump Location	Pump Speed Limits/Flow	Device Illustration
HeartMate II Thoratec Corp./ St. Jude Medical	BTT/DT	Axial flow 6,000-15,000 rpm	Intraperitoneal space	Up to 10 L/min of flow	
HeartWare HVAD HeartWare International, Inc.	BTT/DT?	Centrifugal flow 1,800-4,000 rpm	Intrapericardial space	Up to 10 L/min of flow	
HeartMate III Thoratec Corp./ St. Jude Medical	Under investigation*	Centrifugal/ fully magnetically levitated flow 4,800-6,500 rpm	Intrapericardial space	Up to 10 L/min of flow	

Fig.3. Commercially available MCS devices.

II. CFLVAD & PFLVAD

Brief operation of Continuous flow left ventricle assist devices (CFLVAD) and Pulsatile flow left ventricle assist devices are given in this section. Fig.4. shows the PFLVAD. It consists with pusher plates, blood chamber, and one way inflow and out flow valves, motor.

As the names suggest, pulsatile pumps replicate the pulsing nature of the body's cardiovascular system, this was done by moving plate mechanism with linear motion. Typical LVAD having blood pumping chamber, where blood is filled from one way inflow. Pusher plates are associated to motor. Because of the linear motion by motor, pusher plates pushes the total blood in the chamber to aorta through one way outflow valve.

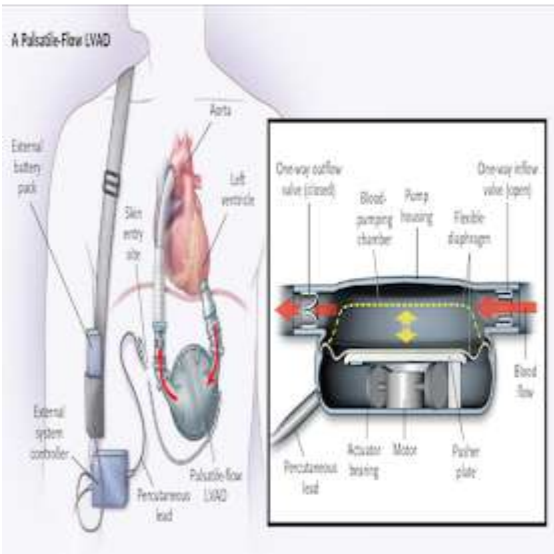

Fig.4. PFLVAD (Pulsatile flow left ventricle assist device)

CFLVAD [11] (continuous flow left ventricle assist device) provides steady flow. Persisting steam diminishes the pulsatility. CF pumps with a magnetically levitating rotor system or hydrodynamic bearings to decrease mechanical wear, theoretically reducing hemolysis and the incidence of pump thrombosis. Rotary based CFLVAD is shown below. Mechanical energy of the rotor helps in pumping the enough blood continuously in CFLVADs. (fig.5.)

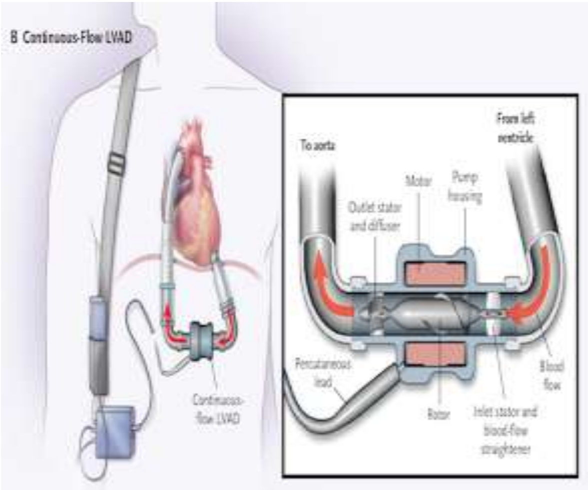

Fig. 5.CFLVAD (continuous flow left ventricle assist device)

III. DIFFE-RENT MOTORS WERE USED IN ARTIFICIAL HEARTS AND RECENT ADVANCEMENTS.

Following are different motors that were used in TAHs and VADs.

A. *Linear motors :*

The decrease in the wear of the inclined parts in the rotary motors results in greater life expectancy and smaller dimensions. Pivoted motors with associated pumps have involved many moving parts. Continuous flow devices with linear motor drives were seen all stages of devices having with lesser wear slanted parts, and was favored for CF devices. And those topologies were either extravagantly weaker or very bulky (an excessive amount of voluminous.) [12]. only one solitary moving part linear motors were seen in earlier stage MCDs. With the true objective of LVADs and TAHs, warm incident higher than 19 W - 22 W isn't continued on by the human body (human body is not tolerable for more than 19 W to 22 W). So reduction of dissipation heat is major challenge in TAHs and VADs. Because more heat dissipation in the body may lead to loss of life in patients. Based on magnetic force simulation, direct linear drives for a TAH were reported in [13] and those devices were accomplished weight, force, and size requirements [13]. Rotational pump based devices were comparatively not good to platelets, which was represented in [14]; blood pumping capacity is outstandingly poorer MCDs with linear motors. Furthermore, they in like manner experienced steadfastness issues, which all are represented in [14].

B. *Double stator motors :*

Linear motor associated devices are failed to get proper blood flow. To improve the flow rates to requirement, double stator motors were introduced in [15] [16]. They were accomplished proper flow requirements of the body. Flux in double stator motor was nearly double the previously linear motors. This was achieved by double stator structure, higher flux lead to higher force density for higher flow rates. Double stator motors were robust in structure.

C. *Tubuler Double stator structure and a vernier topology motors :*

Tubuler Double stator structure & vernier topology (TDS-VPM) motor was proposed in [17] for the purpose of TAHs and VADs. This motor possesses two tubular stators, one tubular mover and eight embedded PMs, offering the advantages of high reliability, robust structure and improved power density. It has also confirmed that the double-stator topology with a special angle difference may significantly altogether lessen the cogging power. Therefore, the TDS-VPM is very promising for low-speed high-thrust applications such as artificial hearts.

D. *Permanent magnet synchronous motor :*

Initially proposed PMSM designs for heart pumps were made with an impeller, motor. Both together associated by a common shaft. Those deigns were required mechanical coupling. And it was done by mechanical bearing. The most significant drawbacks in such an artificial heart lie in the formation of blood clots on the bearing and shaft, deficient sealing, and bulky volume. Fig.6, which were avoided in magnetic coupler design. Fig.6, and magnetic bearing type design also introduced as revised design in [18] fig.6. This is simpler in construction and smaller in size than before developments. The maximum speed reported with magnetically suspended type design about to 730 r/min.

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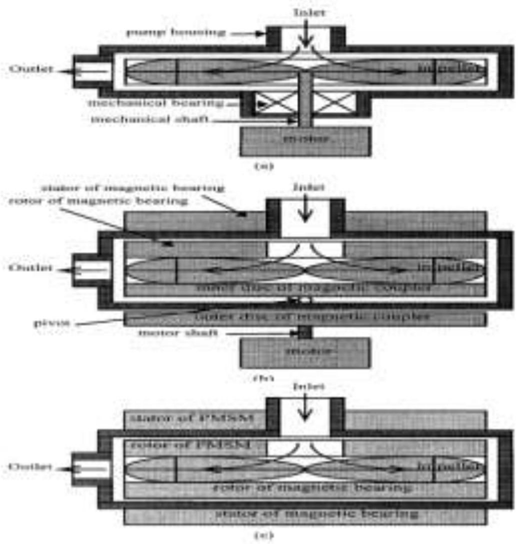

Figure 6. TAH with PMSM. (a) Motor coupled to impeller. (b) Motor coupled to magnetic couplers. (c) Magnetic bearing design.

Lesser size and weight was accomplished with stream liner pumps by set up of mag lev technique. [19]. with a particular ultimate objective to diminish the size and weight of the pump, change of the rotory device setup is of unbelievable hugeness. As of late BLDC motors are getting request in modern and restorative applications because of their points of interest like diminished size and weight, high viability, improved trustworthiness and extraordinary control qualities in a wide speed run. [20].

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A. Axial self bearing motor :

With the target of building up a little blood pump with a suspended rotor, authors in [21] propose an outline conspire for an axial type self-bearing motor. The axial type motor, which is fundamentally made out of a disc/plate motor and a pivotal attractive bearing, controls both the motion and the hub interpretation of the rotor. Which is almost like the bidirectional plate machine, aside from changing the extents of the two sides of the flux to control the pivotal appealing power. In any case, the circular and tilt headings depend on uninvolved strength, and, along these lines, the rotor has poor damping which may make harm blood constituents. The outline incorporates a hydrodynamic bearing for enhancing radial help properties. Experimental prototype of this motor were seen in [21], it was constructed and incorporated into a mixed flow blood pump. The outcomes demonstrated that the bidirectional axial type self-bearing engine had high proficiency as a little continuous stream blood pump, conveying adequate stream rate and pressure head. The pump created and depicted beforehand had a high enough stream rate and weight set out toward utility as a heart pump. Consequently, a hemolysis test was done utilizing bovine's blood. Normally, the radial pump is considered to cause less hemolysis because of its low speed. The test conditions were as per the following: speed 3100 r/min, stream rate 4.08– 4.20 L/min,

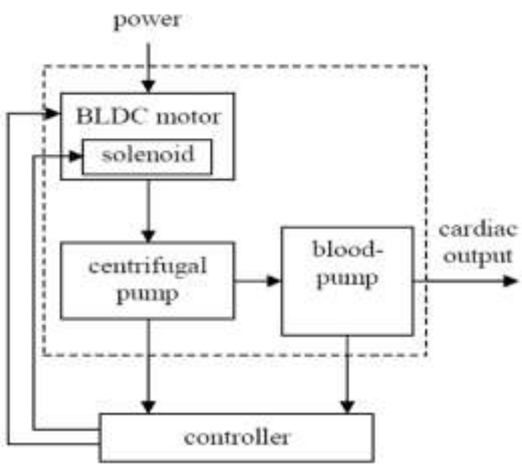

Figure.7. Block diagram of drive system.

A double mixed flow pump equipped with the proposed axial self-bearing motor was designed and fabricated, and is schematically shown in Fig. 8. In this pump, hydrodynamic blood bear- inks were used on the both sides of the pump. An image of the assembled pump is shown in Fig. 18. The inlet blood flow is diverted to both sides of the mixed flow pump, and both then flow into the center pole of the rotor. The blood is then pumped by both sides of the mixed flow blades. The pressurized flows merge in the middle of the rotor to the outlet port. We consider that the main merit of this configuration is the high flow rate relative to its small size.

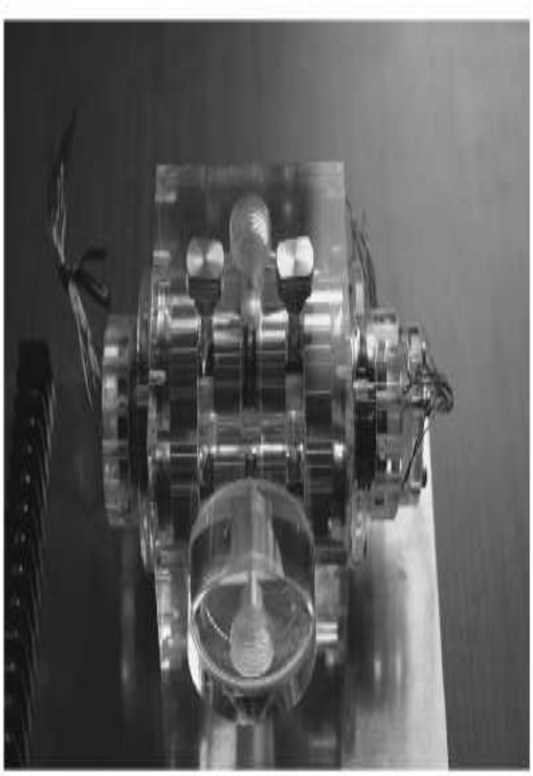

Fig.8 mixed flow pump [21]

Several currently used devices are shown below.

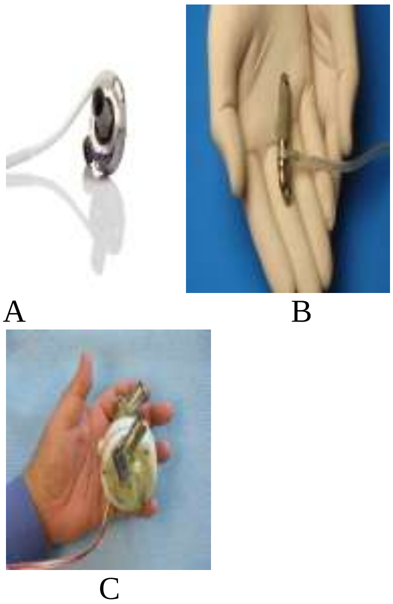

Figure. 9. (A) ThoratecHeartMates III leftventricularassistdevice, (B) Jarvik Infant device, (C) Continuous-flow totalartificial heart.

IV. Energy transmission

Energy transmission to the motor-pump for the implantable TAHs and VADs is done in two ways.

1. Percutaneous cables
2. Transacutaneous energy transmission (TET) system

Percutaneous cables are used to transmit the Electrical energy from outside battery source. Cables go through the skin and connected to the inside motor. Fig.10. shows the percutaneous cable system. percutaneous driveline poses constant risk to bacterial colonization and infection due to percutaneous cable.[22]

And another new developed system is Trasacutaneous energy transmission (TET) system.[23][24]. This is an enhanced system, has an advantages than percutaneous cable system. Percutaneous cables are totally eliminated in TET system. It is totally wireless based system.

TET system transmit the energy from outside source to internal battery without any usage of cables or wires.TET system is having two TET coils, one is inside of the chest, another is at outside of the skin. Outside TET coil is connected to external charger, and inside TET coil is connected to internal battery. Wireless energy transmission takes place through mutual induction. Fig. 11. shows the TET system. Abiocor artificial hearts are totally implantable devices.

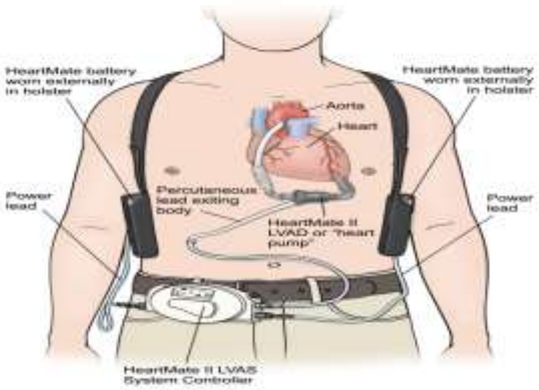

Fig.10. percutaneous cable type energy transmission system

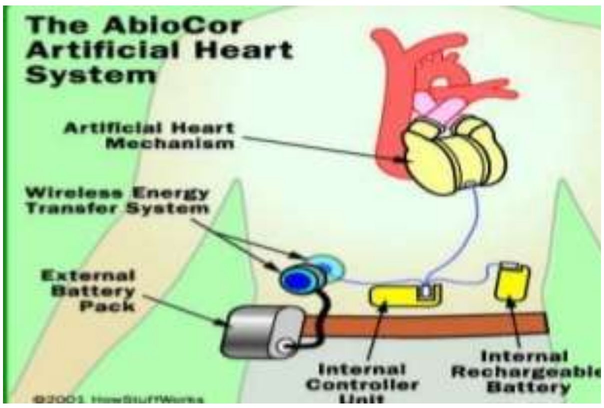

Fig.11. TET based system.

V. CONCLUSION.

Pusher plate dependent pulsatile devices are complex in nature due to reciprocating type. And Continuous flow devices are simpler by introducing rotary mechanism instead of reciprocating type. But pulsatile index in CFLVADs are very poor. It leads to so many issues, which are already mentioned. So it is required to introduce the pulsatility in CFLVADs, by various pulsatile algorithms. And it is concluded from literature, among the all CFLVADs Maglev based devices are reliable, due to avoidable nature of blood cell damage. It was reported that inefficient sealing with mechanical bearing leads to platelets damage, which is avoided with Maglev type designs.

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