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Simple Mechanisms, Technologies to Innovative Applications & Recent Mechatronic Value Additions

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Abstract: The technologies & concepts that were developed decades & centuries back, lying dormant got rejuvenated & redeployed by the recent strides in Electronic, Automation & Mechatronics fields. Computing & communication sectors had been playing pivotal role in this gainful redeployment of old techniques. Few of them are briefed in this paper along with the developments with integration of new innovative Mechatronic technologies. The technologies that are covered in this paper are: (1) Four square Method of Testing Mechanical Transmission elements - Testing Mechanical transmission components in Automobile industry; (2) Flywheel Energy Storage systems (FESS) – Non conventional Energy storage system; (3) Four bar linkage mechanism or Double drag link transmissions gainfully employed in Paper Roll to sheeting lines; (4) Deployment of Differential transmission in Horizontal Centrifuges – Solid Liquid separation; (5) Power generation in river canal upstream using Archimedes screw turbines. The paper also dwells on the technical intricacies in each application including brief on evolution of basic concept of each of the above application. Few applications details also explained in detail here and identifies sectors of industries that got benefitted out of such adaptations. The paper tries to prove that no intellectual thinking is a wasted effort and surely the concepts culminate in to great applications. It is an effort of the paper to evoke intellectual interest of the reader to identify simple solutions to a complicated problem through right mix of Old concepts & current day developments by siting examples & details.

Keywords: Servo Motor Systems, Paper Sheeters, Draglink Transmissions, Solid-Liquid Separation, Automobile Transmission Testing, Energy Storage, Four Square Method of Testing

1. Introduction

Referring to the following observation by Nobel Laureate Dr Herbert Kroemer, who stated "[1] certainly when I thought of the hetero structure laser, I did not intend to invent CD Players. I could not have anticipated the tremendous impact of fiber optic communications. The person who come up with applications thinks differently than the scientist who lays the foundation" which shows how a concept/ development/ innovation becomes successful with Application engineers finding new venues and horizons of application. The same had happened to all the iterated technologies which were conceived either in BC or 200/ 300 years back. The latest that can be cited is the Synchronous On- the fly sheeter for paper/ plastic films/ Metal plates – roll to sheeting equipment. Each individual application is threadbare discussed from the angle of deployment of age old technologies mixed with new innovative developments.

Application engineering compliments the core technology concepts, design & developments in manufacturing technologies conceived earlier times with the help of current day developments in allied fields. It is needless to impress the importance of application engineering in the development & gainful innovative application of yesteryear concepts/ technologies as it had manifested its considerable support in the development of DC motor development in the early 20th century which had paved the way for further developments for industrial applications with variable speed & position control requirements. It is a pleasure to iterate few examples of past years/ or ancient ideas and technologies revitalized & deployed productively for improvement of quality or increase in productivity or to meet the current market demands across all the industrial verticals. Most of these examples have become successful mainly due to strides in Electronic control technologies and developments in the basic mechanical approach, adaptation of developments in computation &

communication engineering as well as material science. Mechatronics has supported the old ideas rejuvenation and at the same time impressing and highlighting virtues of basic conventional engineering. Mechatronic developments that have improved the performances of age old mechanical systems are also discussed. Any ideas however basic they are or whenever they were conceived, can be rousingly successful even at much later times if appropriately applied.

2. The Old Technologies & New Applications

a) Four square method of testing mechanical transmission elements:

It all started with tensile test nearly 90 or more years ago. Initially twist was given to static mechanical transmission member & tested for its stability & integrity after the test. With the application of differential transmissions (planetary transmissions) and the controlled torqueing mechanisms, the tests could be conducted & monitored at variable speeds and at different controlled torques. This in conjunction with advances in torque transmitting devices, field instrumentation & digital communication, it became very much possible to measure torque, speed at the test elements levels & log in the results in remote computers for effective analysis & decision making. A typical four square test facility is as per illustration Figure 1 below used for a tractor transaxle testing. The basic principle is to loop the power within a closed loop of mechanical transmission set up of back to back arrangement with torqueing mechanism through torque controlled clutches like Electromagnetic Particle clutches/ Pneumatic clutches.

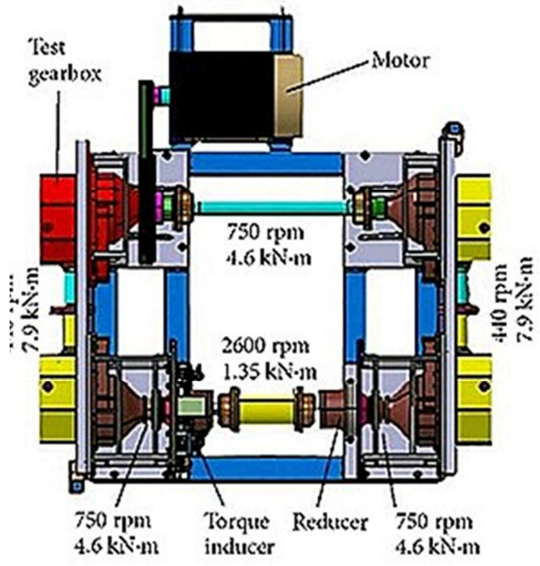


Figure 1. *Tractor Transaxle Four square testing [4].*

This had reduced the complexity in testing high/ ultra high power mechanical transmission testing at their rated torque & speed levels without having to have such high power rating of prime movers. In fact these arrangements require only fraction of rated power of the components under test power specifications to the tune of barely 20-30% of the test components rated specifications. Aerospace, windmill, power & automotive etc. sectors had got the benefits tremendously from this type of testing.

b) Flywheel Energy Storage systems

Figure 2. *Aerospace & wind mill gear box test equipment [10].*

The technology was used nearly 6500 years back in the form potter's wheel. Initially the fly wheel technology was rather used for storing the kinetic energy and expending it short burst of energy with in a cycle of operation when sudden load appears in the system like power pressing or a steam locomotive or cutting Paper / plastic films/ Metal sheets with a single Cutter drum cutting the web in rotation. In these applications the flywheel discs were located on the high speed shafts Subsequently with the advent & developments Motor generators, the flywheel was located on these motor generator shafts to convert the kinetic energy to potential energy whenever power to the MG sets failed and theses were horizontal installations with speeds maximum up to 3000 rpm. The kinetic energy is proportional to speed & proportional to square of radius of flywheel. And air drag & bearing friction losses at ultra-high speeds were phenomenally high & in conjunction the radial loads due to horizontal mounting on the bearings were also found to be increasing the bearing friction losses etc. facts were pushing for development of alternative high efficiency technologies. So the vertical mounting design was conceived along with magnetically levitated high speed bearings, High density carbon fibre rotors that can withstand extraordinary centrifugal forces at these ultra- high rotational speeds, Permanent Magnet Motor – generator solid state technologies and with vacuum encasing reduced the net losses considerably and the same age old mechanism was modified for successfully integrating above technological developments to come out with a strong contender for Alternative Renewable Energy storage systems- which is the need of present day world.

Figure 3. *Potters wheel & Trevithick's 1802 steam locomotive using a flywheel to evenly distribute the power of its single cylinder to present [5].*

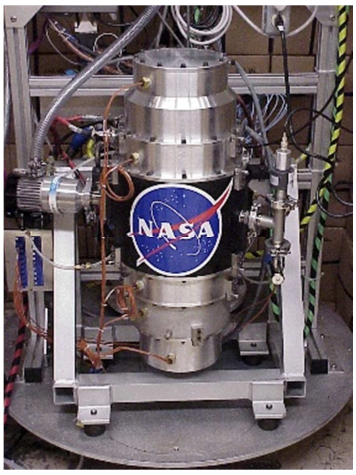


Figure 4. *G2 Present day Flywheel Module, NASA [5] & future.*

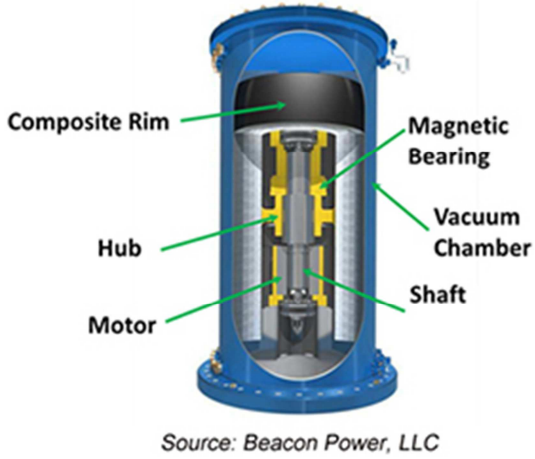


Figure 5. *Beacon Power – Flywheel Storage systems [11].*

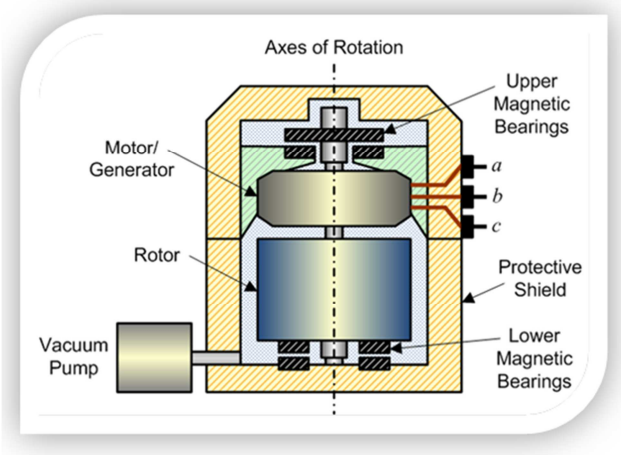


Figure 6. *Fly storage schematic [12, 13].*

$$E=\frac{1}{2} I\omega^2 \text{ or } E=\frac{1}{2} (kMr^2)\omega^2$$

I stands for Fly wheel's Moment of Inertia
ω=rotating speed in radians per second.
M=Flywheel's Mass
R=Flywheel's Radius,
K=Inertial constant [15]

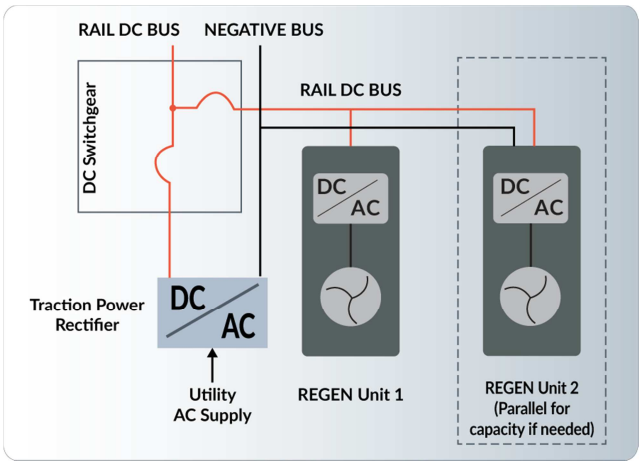


Figure 7. *Vycon Energy Flywheel Energy system [6].*

c) Four bar linkage mechanism or Double drag link transmissions gainfully employed in Paper Roll to sheeting lines.

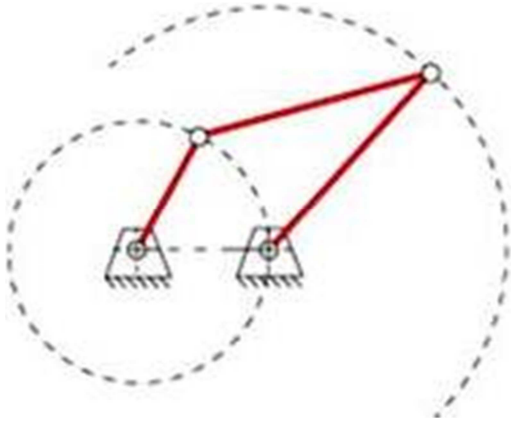


Figure 8. *Grashof criterion – Four bar linkage [2].*

As per Grasshof's criterion for a four-bar linkage as per Figure 6., considering short link is the fixed link, the sum of the shortest and longest link of a planar quadrilateral linkage is less than or equal to sum of the remaining two links, (s+l < p+q) then the both the links can rotate fully but when the input rotates at constant rotational speed, the output rotates with varying rotating speed.

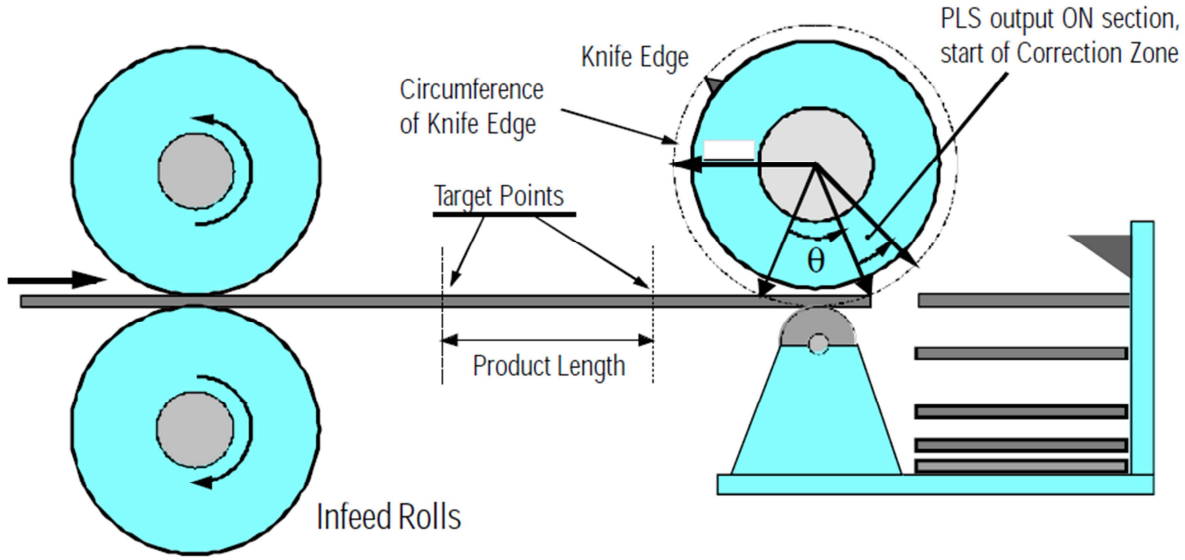
The above was found to be exact requirement for cutting the paper roll in to sheets at high cut length accuracy as well as diagonal accuracy with the help of double cutter drums making scissoring action rather than shearing action. This arrangement was successfully employed in paper roll to sheeting line to get perfectly square/ rectangular sheets avoiding parallelogram sheets with cut length accuracies better than + 0.5 mm on equipment operating at speeds > 100 mtrs/min. This successful application further improved by employment of Servo motors with cam profiled servo drives helping equipment reach speeds up to 350 mpm while maintaining excellent cut length accuracies better than + 0.38 mm.

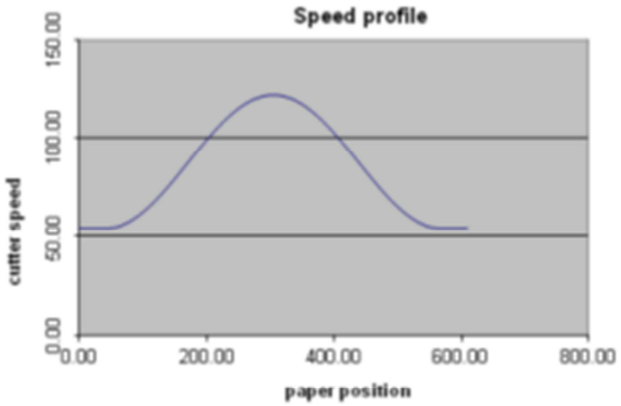
From 1980s when Servo drives with DC Servomotors had evolved, the same were extensively employed in the

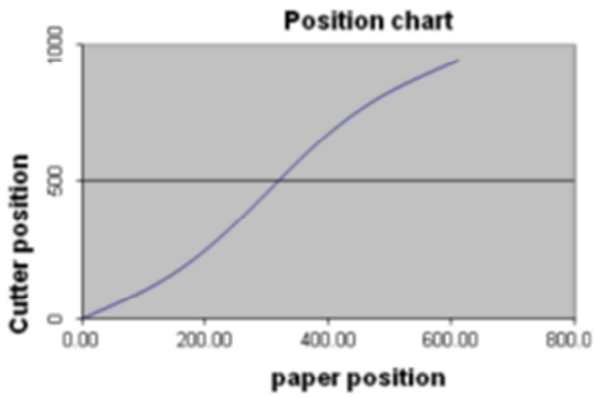
application throughout the world. Subsequently from millineum year onwards with AC Servo technology developments both in motors & drive technology like Permanent magnet rotors & Feed forward control algorithms, AC Servo drive with AC Servo motors are deployed in all the current built machines. This has yielded machine operation performances with accuracies better than +0,38 mm and at speeds above 350 mtrs/ min.

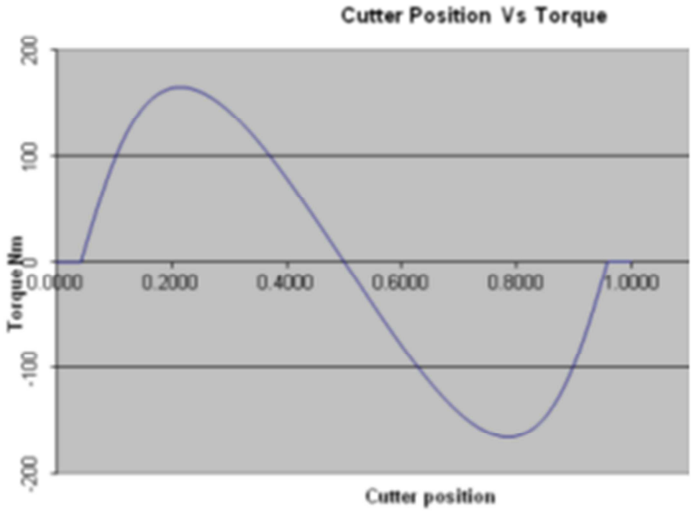
There were three possible cam profiles that could be perused

1) Triangular,
2) Sinusoidal
3) Trapezoidal speed profile graphs for the application are illustrated below:









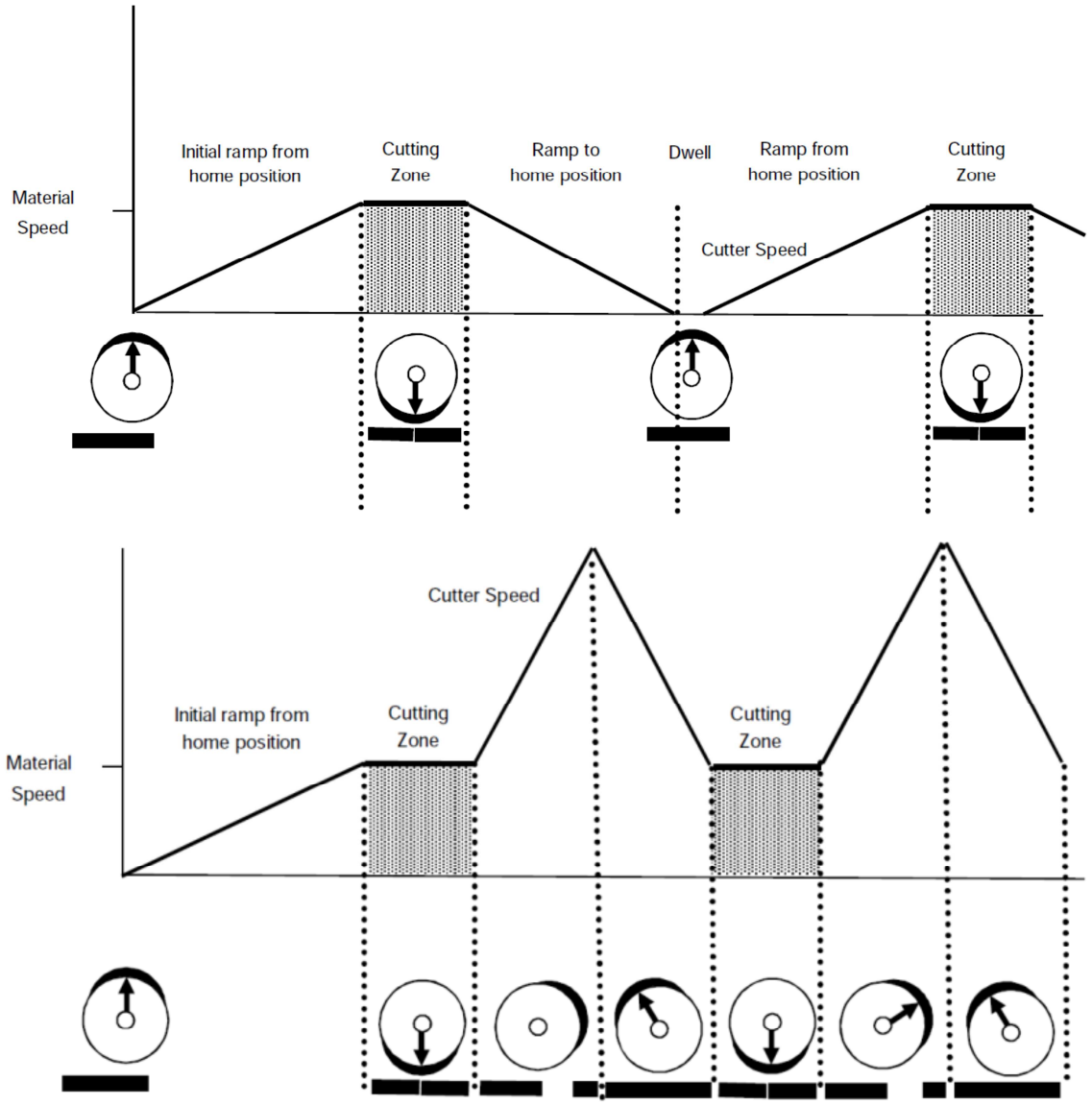


Figure 9. *Cutter Cam Motion profiles [8].*

Comparison of Cutter Motion profiles:

COMPARISON OF CUTTER MOTION PROFILES				
Sr. no.	**Parameter**	**Trapezoidal Profile**	**Triangular Profile**	**Sinusoidal Profile**
1	Acceleration	Least constant throughout speed change	Higher than Trapezoidal and constant throughout speed	Varying continuously and highest peak
2	Speed transition points	Abrupt. To introduce smoothening formula at transition point for smoothening	Abrupt. To introduce smoothening formula at transition point for	Naturally smooth
3	Peak speeds	Higher than Triangular	Least among the profiles	Highest among the profiles
4	Mechanical transmission suitability	Fairly OK	Highest stress on Transmission	Lowest stress on Transmissions

Figure 10. *Comparison of Motion Cam profiles [8].*

d) Differential transmissions in Horizontal Centrifuges

Another application which had proved century old technology as the effective technology for achieving desired performance is the Horizontal Centrifuge used for Solid – Liquid separation.

The Horizontal centrifuge requires following for achieving effective required solid-liquid separation.

1. The bowl has to rotate at high speeds to generate centrifugal forces for sedimentation of solids on the inner surface of the drum.

2. The cross sectional area to meet with required clarification area necessary for containing the solids.
3. The Screw speed to be either higher/ lower than that of bowl creating differential speed for transporting the solids out of the equipment.
4. The hydrodynamic design has to meet the turbulence requirements.
5. The conveyor and beach sections to be optimally designed for efficient solids transportation.

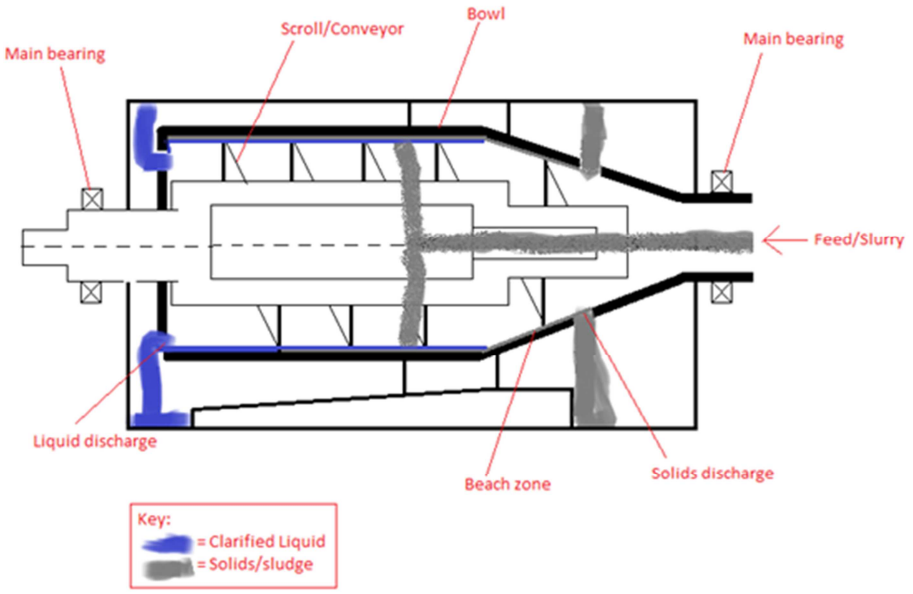


Figure 11. *Horizontal Centrifuge for Solid – Liquid separation [8].*

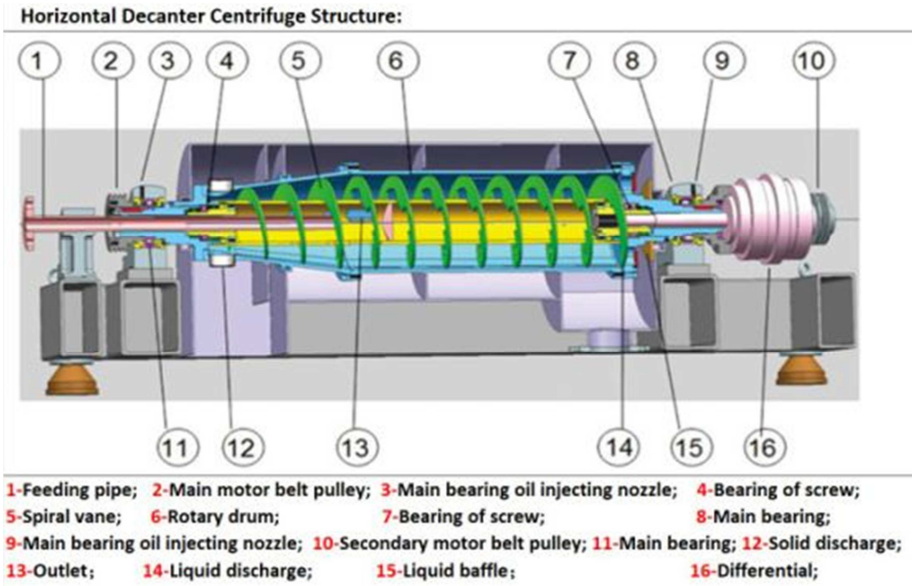


Figure 12. *De Canter (Horizontal centrifuge) cut section [17].*

Principle of operation

As can be seen in the above illustrations, the waste liquid with solids goes in to chamber of the centrifuge thru inlet pipe and due to high centrifugal forces, the solid particles get deposited on to the bowl inner face. These solids get pushed outward by the spiral vanned screw which is concentric to bowl and working at either higher/ lower speed than the bowl. This differential speed is created by a planetary/ cycloidal gearbox as per differential required due to inherent characteristics of differential transmission.

As per Wills equation of planetary gears [16]:

$$nr \cdot zr = nc \cdot (zr + zs) - zs \cdot ns$$

Wheras
ns=Sun gear speed
nc=Carrier gear speed
nr=ring gear speed
zr=ring gear no. of teeth
zs=sun gear no. of teeth
With the above the body of gear box is coupled to main

motor through belt & pulley. The sun gear is coupled to either a brake/ clutch/ Four Quadrant driven motor to control the differential speed between Bowl & screw a constant by a closed loop feed back controls:

1. The bowl is driven by a main motor through belt & pulley.
2. The other end of rotating bowl is body coupled to planetary gear box as input to the carrier gear.
3. The planet gears (output) are coupled to screw and sun gear shaft is coupled to a brake or drive.
4. Earlier times it was Pneumatic disc/ Eddy current brakes/ clutches for braking/driving torque control.
5. Presently through 4 quadrant AC drives & motors so that sun gear can be precise speed & torque controlled in differential to carrier gear there by achieving differential speed between screw & bowl to ultimately squeeze the liquid from solid for an effective solid – Liquid separation.
6. There are two possible speed situations for solid – liquid separation.
7. Screw rotating at higher speed than bowl & second the screw rotating at lower speed than bowl. These two situations are obtained either by deploying Planetary [Figure 13] or by Cycloidal [Figure 14] differential gear transmissions.

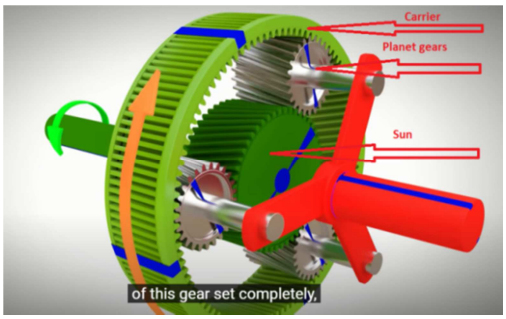


Figure 13. *Planetary transmissions [14].*

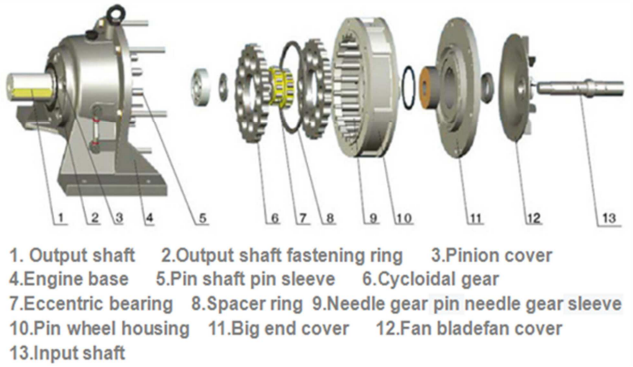


Figure 14. *Cycloidal transmissions [15].*

e) Archimedes Screw turbines for power co generation of power

One of the oldest concept conceived 2300 years back by Archimedes got redeployed as alternative power generation as micro power grids &for small remote communities especially tapping the energy potential in canal upstream flow of low pressure heads. Archimedes principle of screw is employed to generate power avoiding pollution due to other types of power generation like thermal/ nuclear etc. A double start closed trough screw turbine designed to give power output of 5kW, where the available head was 5m, with the outer diameter of the turbine 1.5m and the length of the turbine 8m [18].

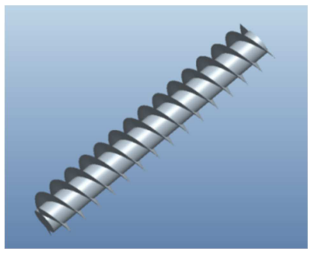


Figure 15. *Archimedes screw turbine 5m head/ 8 mtrs long for 5 kw [18].*

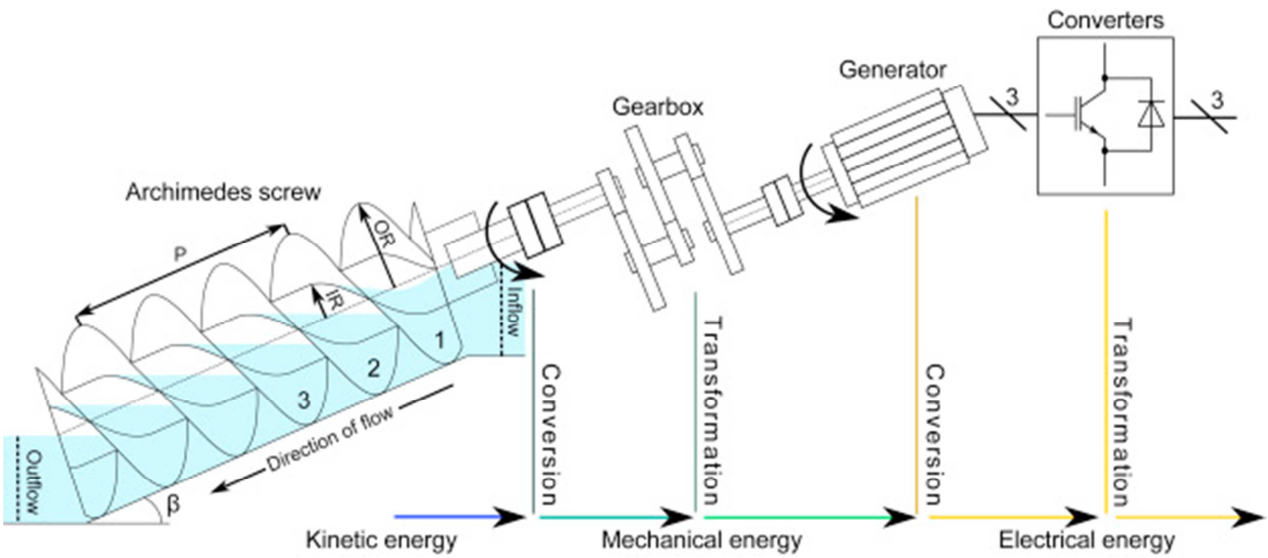


Figure 16. *Archimedes screw turbine schematic power flow diagram [19].*

This technology is being deployed with integration of new induction motor drive technologies for power generation and exporting power to powergrids or using as captive generation purpose. This type of power generation is especially employed in canal upstream as well as urban sewerage plants for small remote communities self sufficiency.

3. Conclusion

Hence it is apparent that concepts of thousands years have been redeployed effectively with Mechatronic developments to achieve the targeted objectives of higher & consistent productivities and accurate performances. This proves that concepts or innovative techniques has come back in to applications strongly with proper upgrades in the supporting tools like Power Electronics, Communication engineering, Telematics & Mechatronics.

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