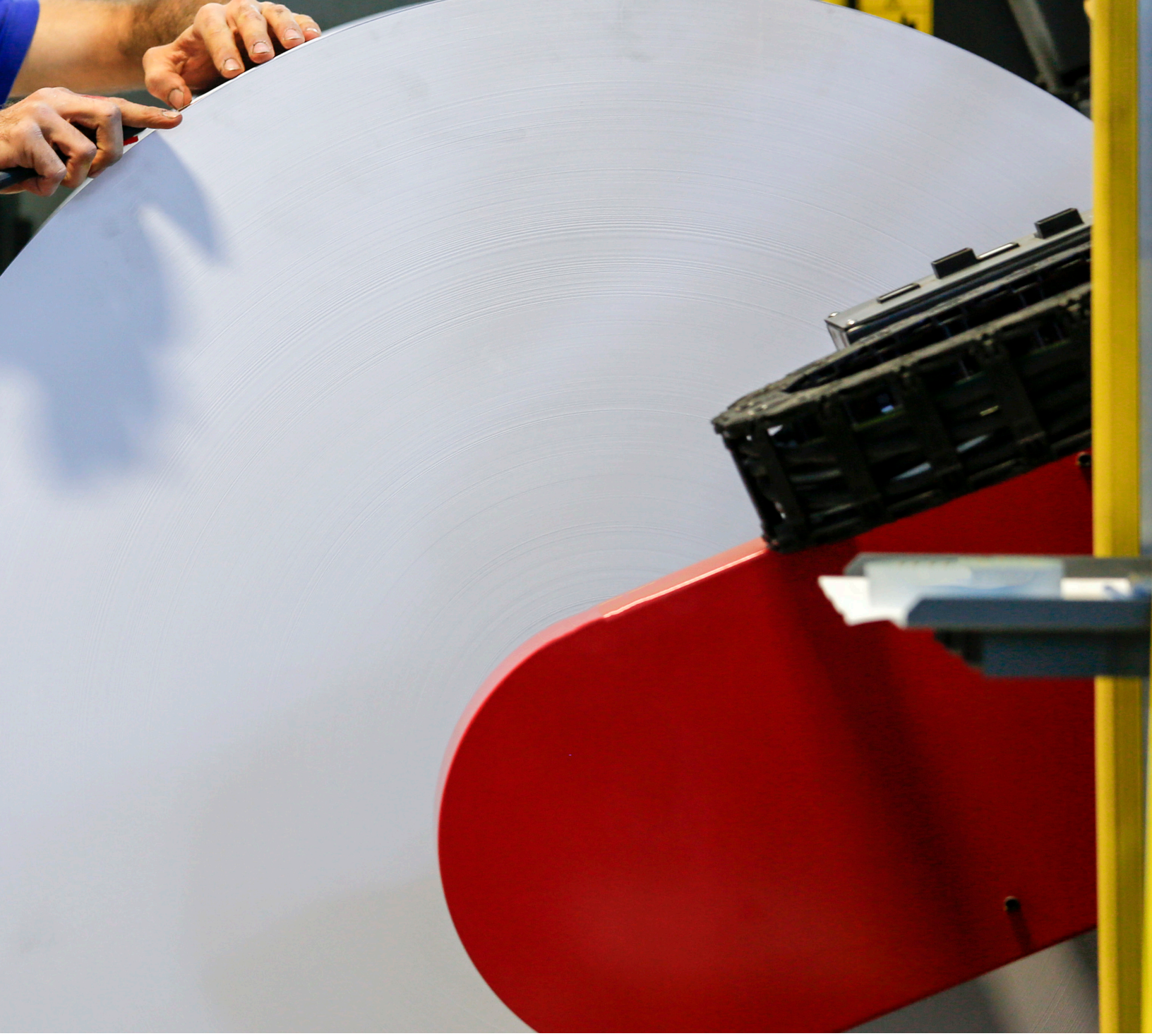


New Winding Technology for Converting Lines

Drive Controlled Pump (DCP) Solutions in the Converting Industry

Parker

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New Winding Technology for Converting Lines

Paper converting lines employ surface, center, and center/surface combination winders and each winding technique has inherent benefits and limitations. The primary goal of this paper is to detail how Parker's Drive Controlled Pump (DCP) Technology can make center winders the ideal winding technology for the converting industry.

Introduction and Review of Winders

Surface Winders

The winding material roll contacts one or more driven drums rolls and the power to wind the winding material roll is transmitted from the driven drum roll to the winding material roll's outer surface. Generally, these winders can only wind in one direction due to the complexity of splice and transfer mechanisms. The single drum winder, *see Figure 1*, mainly relies on the nip principle to wind the material. Nip loading is the method of supplying and controlling adequate traction between the driven drums roll and the winding material roll. Dual drum surface winders, *see Figure 2*, employ slight differences in speed (RPM) between the driven rollers, which is achieved by varying the torque between these rollers.

Under constant tension, the winding torque of a Single or Dual Drum Surface winders do not change* with the roll's ever increasing diameter, therefore their drive systems can be simple and use much smaller motors than a more complex center winder. Even though Surface and Center winders use different size electric motors they all use the same amount of energy to wind similar rolls.

Typically, material rolls with large build-up of both extensible and non-extensible materials are wound with surface winders, especially if the material is not sensitive to nipped winding and/or compression, such as craft paper, textiles, etc. In general materials that are sensitive to surface damage such as scratching and/or loosely wound finished rolls are not recommended for surface winders.

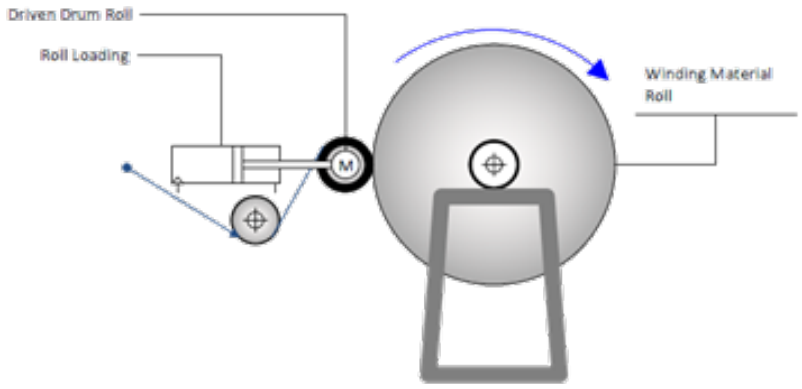


Figure 1: Single drum surface winder

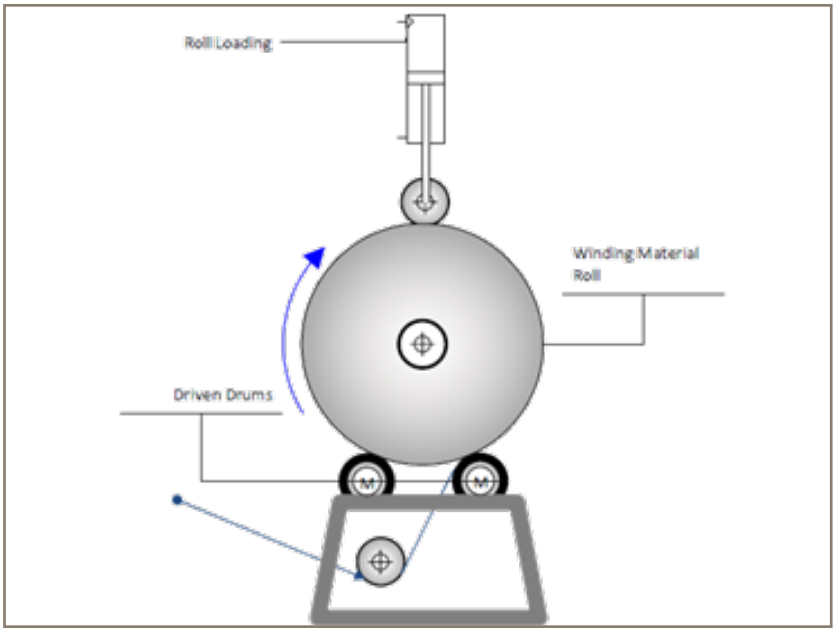


Figure 2: Dual drum surface winder

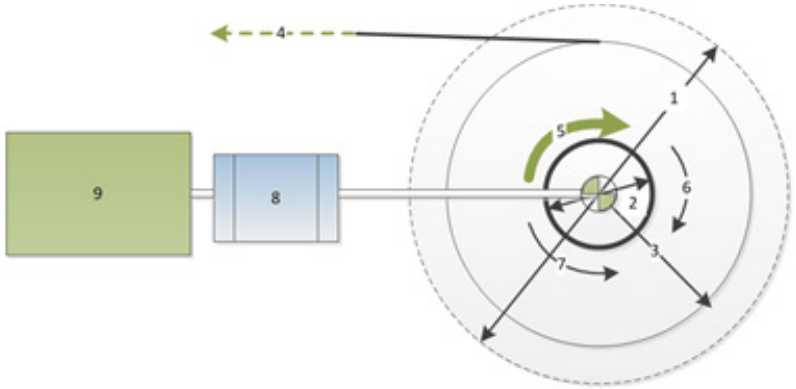
* (Excluding bearing losses due to increasing roll weight)

Discussion

Center Winding Process

This process is also known as winding, or rewinding, in this document we will refer to it as “winder” for simplicity. “winder” refers to both the over and under winding and unwinding processes, unless otherwise specified. The parameters that effect the winding process are noted below.

1. Full roll OD[I]
2. Core/spindle OD
3. Winding arm
4. Web tension
5. Torque direction
6. Over wind rotation
7. Under wind rotation[II]
8. Mechanical gearbox
9. Variable speed electric motor



Typical winder critical parameters

Center Winders

Center winders offer an efficient way of winding high-quality rolls of sensitive material with complex roll density requirements. Center winders are used in applications where the material is either nip-sensitive, requires low wound-in-tensions and/or sensitive to compression during winding. In comparison to a comparable size surface winder, a typical center winder requires an electric motor that can be four to 10 times larger.

Winding is a fine balance between speed and torque. When winding, the roll increases its circumference; therefore, on every rotation a greater length of material is consumed. To keep up with the flow of material, the winder must slow down with every added layer. This build up also increases the winding arm length; therefore, to maintain tension[III] the winder must increase torque proportional to the roll diameter.

To explain this phenomena, the example below is chosen to demonstrate how electric motors are sized for electromechanically and hydraulic winder drive systems.

Roll Buildup

Winder buildup is the ratio of full roll diameter to its core OD, for this example a 72” roll with a core OD of 6” has a 12:1 build.

Example Assumptions

Maximum web (line) = 2,000 FPM
Web Width = 72 In
Core Diamter = 6 In
Full Roll Diamter = 72 In
Maximum Web Tension = 4 PLI (Lb_f per linear inch)
Taper Tension 1:1

[I] Outer diameter
[II] Under wind application is like over wind, therefore all diagrams and processes refer to over wind method
[III] For simplifying the argument, taper tension is ignored

Winding Torque

To maintain tension, the winder motor must produce enough torque to pull the material at the desired process tension. The resultant torque is transmitted to the spindle by an electric motor and gearbox; the required torque can be calculated by multiplying the web tension by the roll radius. As the roll builds up, the required motor torque increases proportionally. In this example, 72" wide web running at 4 PLI demands 288 Lb_f of tension resulting 72 Ft-Lb of torque at core. As roll builds up with 1:1[IV] taper tension, torque increases from 72 Ft-Lb by factor of 12 to 864 Ft-Lb.

Torque
Tension force: Tension × web width = 4 PLI × 72 in = 288 Lb_f
Winding torque at core: Tension force × winding arm at core (Core Radious) = 288 Lb_f × 6" ÷ 2 ÷ 12 = 72 Ft-Lb
Winding torque at full roll: 288 Lb_f × 72" ÷ 2 ÷ 12 = 864 Ft-Lb OR Core torque × build up = 72 × 12:1 = 864 Ft-Lb

Winding Speed

To maintain tension, the winder must keep adequate rotational speed, meaning a roll must match its surface speed to the incoming web speed. The spindle speed is calculated as web speed divided by the roll circumference; for a web speed of 2,000 FPM, in this examples a 6" core roll must turn at 1,273 RPM. At 72" full roll, the spindle has to slow down by the buildup ratio to 106 RPM.

Speed
Winding speed at core: Line speed / Roll circumference = 2,000 FPM / (6 × π ÷ 12) = 1,273 RPM
Winding speed at core: Line speed / Roll circumference = 2,000 FPM / (72 × π ÷ 12) = 106 RPM
OR Core Speed / build up

Winding Power

For this example, we are going to assume that line speed and web tension remains constant during the roll buildup. Following these assumptions, the winding power will remain constant and equal to the web horsepower.

Power
Web power: Tension (Lb_f) × Line speed (FPM) ÷ 33,000 = 288 Lb_f × 2,000 FPM ÷ 33,000 = 17.45 HP
Winder power at core: Spindle speed (RPM) × Spindle torque (Ft-Lb) ÷ 5252 = 72 × 1,273 ÷ 5252 = 17.45 HP
Winder power at full roll: Spindle speed (RPM) × Spindle torque (Ft-Lb) ÷ 5252 = 864 × 106 ÷ 5252 = 17.45 HP

As shown, winding horse power at core and full roll are the same and they are equal to web horsepower. However, it looks different form the electric motor point of operation. A gearbox output power must satisfy the following:	To take advantage of a 4 pole motor's full speed range a 1.4:1 gearbox is used. Then the electric motor must satisfy the following:	Now, the electric must provide Maximum 617 FT-LB of torque and Maximum speed of 1,722 RPM.
Gearbox Output Power Range	**Electric Motor Power Range**	**Electric Motor Power**
Core: Speed =1,230 RPM	Core: Speed =1,230 × 1.4 = 1722 RPM	1775 RPM × 617 Ft-Lb ÷ 5252 = 208[V] HP
Torque = 72 Ft-Lb	Torque = 72 ÷1.4 = 51.4 Ft-Lb	
Full Roll: Speed = 106 RPM	Full Roll: Speed = 106 × 1.4 = 148 RPM	
Torque = 864 Ft-Lb	Torque = 864 /1.4 = 617 Ft-Lb	

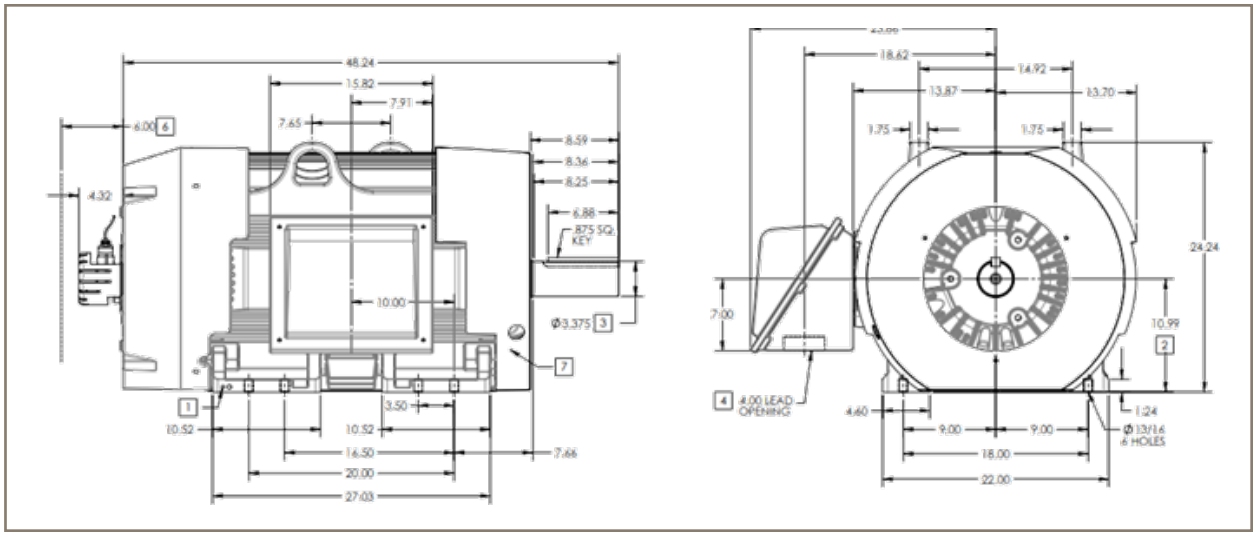
[IV] For computation simplicity 1:1 tension taper profile is considered
[V] A 200HP motor can run at 110% full overload condition.

A question can be asked, why does a winding application require a 200 HP electric motor, 12[VI] times larger than the web horsepower?

Above computation shows drive system at core demand power equal to web horsepower, this power is based on maximum speed at minimum torque. Power demand remains constant throughout the roll build up.

During which torque increases by the roll build up while speed proportionately decreases. At full roll power is demanded from combination of minimum speed at maximum torque. During the buildup maximum speed and maximum torque does not occur at the same time, but electric motor must provide both, therefore it gets larger than the web horsepower by the buildup ratio.

Drive system engineers can take advantage of the constant horsepower extended speed range of variable speed induction motors to reduce electric motor size for winder applications. A 6 Pole 150 HP or an 8 Pole 100 HP motor can equally satisfy the winding requirements, but look at these motor frame sizes.



445T Frame Motor

Part Number	Description	List Price
MBLU10009TEBC	460VAC 100hp 900rpm AC motor TEBC frame:445T TEBC	$27,072.00[VII]
MBLU15012TEBC	460VAC 150hp 1200rpm AC motor TEBC frame:445T TEBC	$29,719.00
MBLU20018TEBC	460VAC 200hp 1800rpm AC motor TEBC frame:445T TEBC	$24,504.00

Since all the above motors have the same frame size, there is no cost advantage to deviate from the standard more popular 4 pole motor. While 6 and 8 pole motors require smaller drives, there can be cost saving associated with drive systems especially if gearboxes can be eliminated, but the selection is a drive system six to nine times larger than web horsepower.

[VI] Equal to 12:1 roll built-up
[VII] A 200HP motor prices vary from brand to brand, speed range, and performance. The above prices are for comparison only.

Drive Controlled Pump

Hydraulic systems are known for their ability to deliver significant power density in a small package. Electric motors and variable speed drives are known for their programmability and responsiveness. Dating back to the 1990s hydraulic and drive system engineers could see the potential for combining the two technologies. Historically, the motion control industry has had limited success combining the technologies. However, in today's manufacturing environment, the higher cost of electrical power, the increasing global concern for the CO^2 footprint and the need for quieter industrial solutions offer opportunities to reevaluate the combined technology. Today, the advancement in new Variable Frequency Drives (VFD) control algorithms, faster programmable VFDs and more efficient hydraulic pumps specifically designed for variable speed applications allows engineers from both technologies to work together with greater opportunities for success by implementing technology known as Drive Controlled Pumps technology (DCP)[VII].

DCP Winding Solution

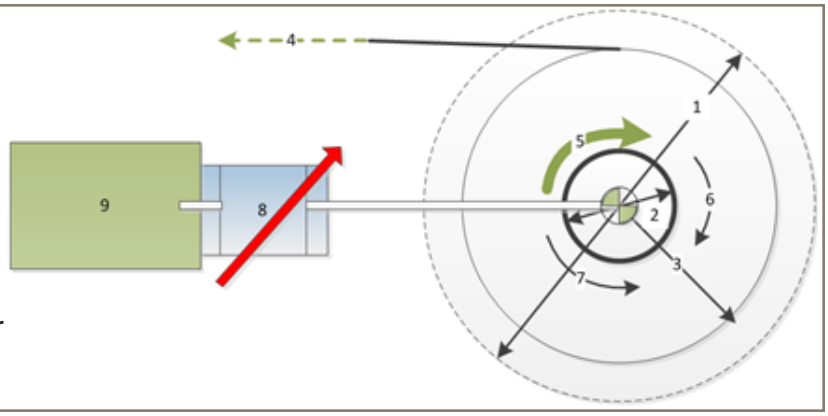
Traditionally electromechanical drive systems are used for majority of converting line's center winders or combined center surface winders. As shown these drive systems use electric motors larger than the web horsepower by the factor of their buildup ratio.

DCP can keep the electric motor size close to its web horsepower by eliminating the buildup factor in winding application. This takes advantage of the continuously variable flow and pressure feature of an electronically controlled variable displacement hydraulic pump operating at variable radial speeds.

In our electromechanical example, a combination of 1.4:1 speed reduction gearbox and a 200 HP variable speed drive was required. For a DCP solution, we can simply replace the mechanical gearbox with a variable displacement hydraulic transmission, which consists of a fixed displacement hydraulic motor and a variable displacement hydraulic pump. The DCP solution will only require a 17.5 HP electric motor for the same application. Below please note the building blocks of this system.

Following are the critical parameters of a DCP controlled winder.

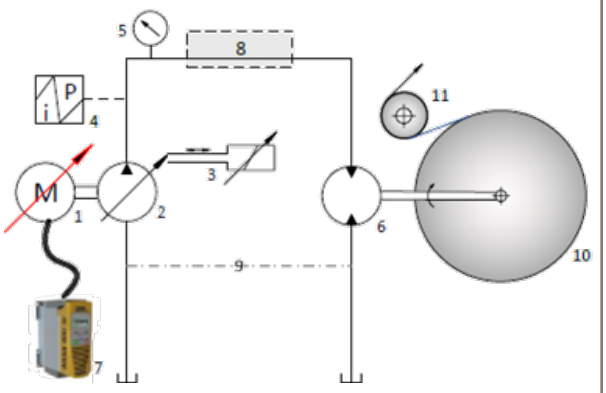
1. Full roll OD
2. Core OD
3. Winding arm
4. Web tension
5. Torque direction
6. Winding rotation
7. Unwinding rotation
8. DCP hydraulic transmission
9. Variable speed electric motor



Typical DCP Winder / Unwinder Critical Parameters

[VII] DCP is Parker technology which combines variable speed drives using custom control macros with fixed or variable displacement pumps

1. Variable speed 20 HP induction electric motor
2. 270cc Variable displacement open loop pump
3. Closed Loop electronic swash plate controller
4. Pressure transducer
5. 2,800 PSI maximum operating pressure
6. 380cc Hydraulic motor
7. AC30V VFD base DCP controller
8. Directional valve for reversing option
9. Closed loop pump for reversing option
10. Winding roll
11. Line speed and tension feedbacks



Simplified DCP Winder Circuit

Variable displacement pump can act as a infinitely variable ratio gearbox to keep the winding power constant throughout the winding cycle. Winding torque and speed parameters for DCP application remains the same.

Any hydraulic system is designed up from its maximum operating pressure. In the following DCP solution, the maximum hydraulic pressure is selected to be 2,800 PSI. Based on this fact, computations below result in use of a 381cc hydraulic motor in combination to a 270cc variable displacement pump requiring 17.5 HP to operate.

When the winder is running at core, the hydraulic pump is set to its maximum displacement and minimum pressure; this allows the hydraulic motor to run at its maximum speed producing minimum required torque. As the roll builds up, the DCP controller decreases the pump displacement proportional to the roll buildup; this will slow the winder down while increasing its torque. At full roll, the hydraulic pump displacement is at its minimum; while pump pressure is at its maximum. This allows the electric motor to produce a constant horsepower equal to web tensioning power requirements of 17.45 HP throughout the roll buildup.

During line speed changes, the DCP controller maintains the pump displacement, yet changes the electric motor's RPM to match the desired line speed. In other words, the variable displacement hydraulic pump is used solely to manage the roll buildup functions, while varying pump speed regulates the web tension[IX].

Mechanical System

Max Line Speed = 2,000 FPM
Line Tension: 4 PLI × 72 In width = 288 Lb_f
Web HP: 288 Lb_f × 2,000 FPM ÷ 33000 = 17.45 HP
Min Winding Torque: 288 Lb_f × 6" Core ÷2 ÷24 = 72 Ft-Lb
Max Winding Torque: Min Torque × Build Up = 72 × 12 = 864 Ft-Lb
Full Roll Speed: 2,000 FPM ÷ (72" full roll ÷ 12 x π) = 106 RPM
Core Speed: Full Roll Speed × Build up = 106 × 12 = 1,273 RPM

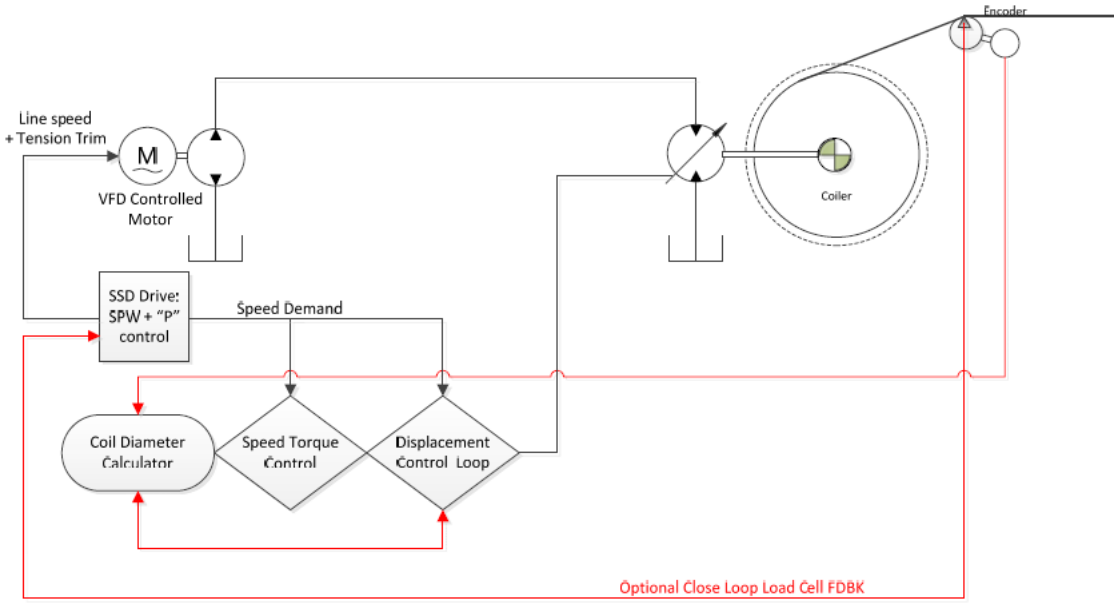
Hydraulic System

Assumption, Maximum Operating Pressure at Full Roll = 2,800 PSI
Minimum Operating Pressure at Core: Max Pressure ÷ Build up = 2,800 ÷ 12 = 233.3 PSI
Hyd. Motor Displacement: Max Torque × 24 π ÷ Max Pressure = 288 Lb_f × 24π ÷2,800 PSI = 23.3 In^3 = 381.5 cc
Flow at Max Torque: 106 RPM × 23.3 In^3 ÷ 231 = 10.7 GPM (10.7 GPM × 2,800 PSI ÷ 1714 = 17.5 HP)
Flow at Min Torque: Flow at Max Torque x Build up = 10.7 × 12 = 128.2 GPM (128.2 GPM × 233.3 PSI ÷ 1714 = 17.5 HP)
Pump Maximum Displacement: Max Flow × 231 ÷ Base Speed = 128.2 GPM × 231 ÷ 1,800 = 16.5 In^3 = 270 cc

[IX] DCP Controller Compensated for pump flow as pressure changes for better tension regulation stability

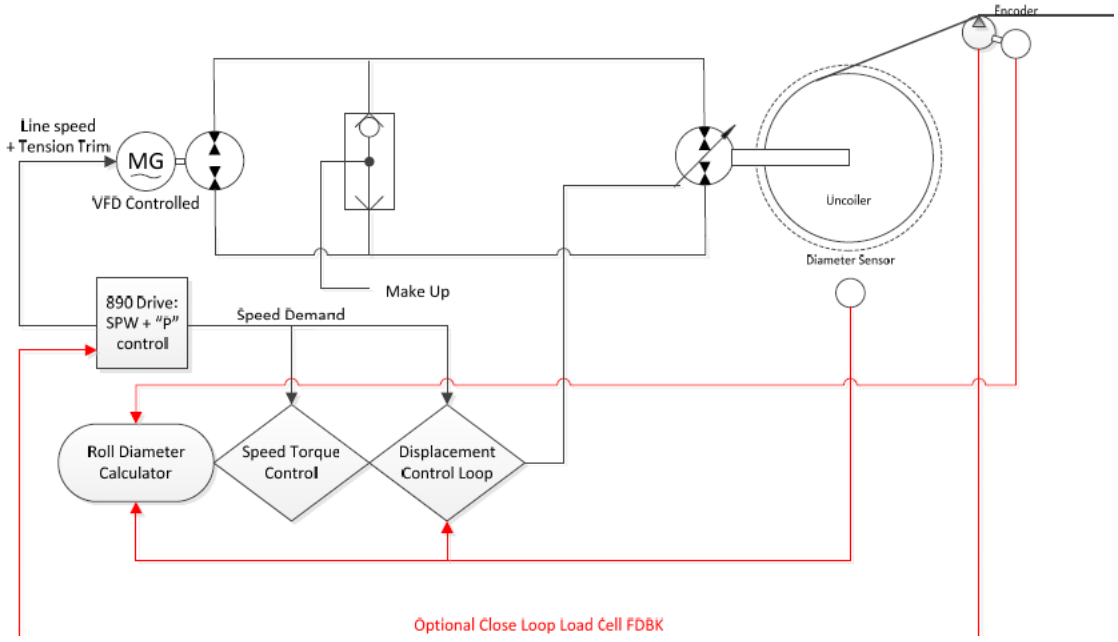
DCP Winding Features

This system is very flexible; a variable displacement motor and a fixed displacement pump can be used to achieve the same results. Following diagrams show the control schematic of DCP winding system using a variable displacement hydraulic motor and a fixed displacement open loop pump.



Simplified DCP Winder Circuit

The system can also be adopted to closed loop[x] hydraulics and unwinding applications quite easily as shown below.



Simplified Closed Loop DCP for Unwinding Application

[x] See reference 11 for typical closed loop unwinder hydraulic circuit

Conclusion

The advancements in hydraulics and variable speed drives (VSD) were running in parallel for many years, but on opposite sides of the fence from each other on solving industrial applications. Once the engineers of both sides met in the middle and shared their knowledge, a door opened to a new way of thinking and problem solving. Combining VSD and hydraulics was difficult at first; the unforgiving nature of positive displacement pumps, the non-compressibility (incompressibility) of the fluids, demanded a different solution than what VSD engineers had experience with more forgiving lower pressure centrifugal pumps. The combination of hydraulics and VSD has created new type of system with lower noise, less components and higher energy efficiencies.

The example above illustrated that the traditional winding requires a 4 pole motor and a 4:1 gearbox solution demands a 200 HP electric motor which is operated by a 200HP heavy duty rated VFD, while web tensioning only required 17.45 HP; this phenomenon becomes more pronounced in finishing and slitting lines where roll buildup are quite high. Using DCP technology, as described in this paper, keeps the electric motor and VFD size down to web horsepower, reducing the cost of electric and drive system and installation. Since DCP technology does not use flow control valves in its hydraulic system, hydraulic losses and heat generation are at a minimum. The technique also simplifies the hydraulic circuits and eliminates complex hydraulic valves, thereby, making the solution more cost conscious, and easier to maintain.

Taking advantage of electric drive and hydraulic technology yields a positive outcome in winding and unwinding techniques. DCP technology allows us to create a wide constant HP range and trade speed for torque during the buildup process while reducing the size requirements for the electric motor. Since this technology operates the hydraulic pump at variable speed; it uses fewer and simpler hydraulic valves. DCP hydraulic systems are less complex and more efficient than traditional hydraulic systems; it operates at much lower noise and temperatures resulting in quieter and cooler surroundings.

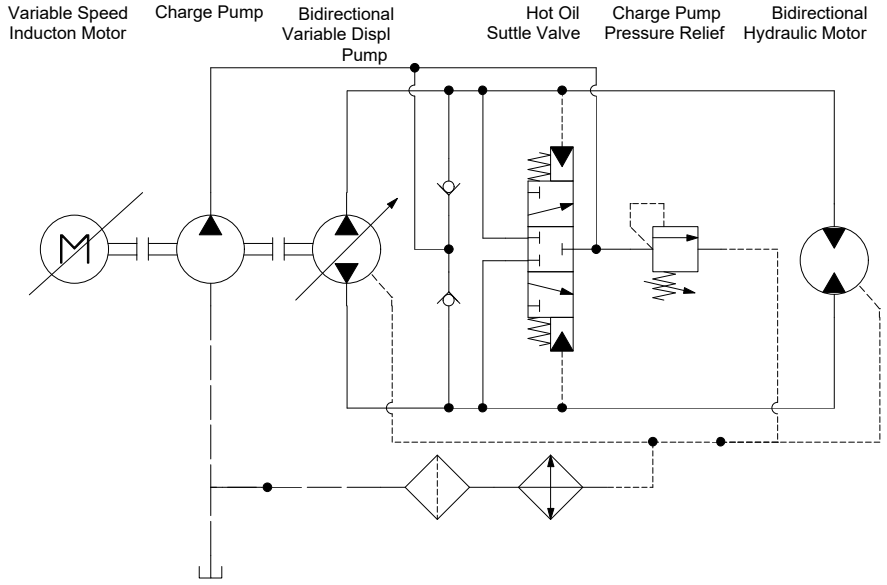


About the Author

Rashid S. Aldun draws on his electrical and fluid power background to create custom drive controlled pump solutions. Prior to joining 16 year ago, he worked as ab industrial manufacturing and fluid power and controls engineer for various OEMs. He has a BSME for Syracuse University.

References

1. Linear Web Power (HP): Tension (LBf) × Web Speed (FPM) ÷ 33,000
2. Torque (Ft-Lb): Power (HP) × 5252 ÷ Rotational Speed (RPM)
3. Acceleration Torque (Ft-Lb): Coil Inertia (Lb-Ft^2) × Speed Change (RPM) ÷ 308 × Acceleration Time (Sec)
4. Coiler Gearbox Ratio: Motor Max Speed (RPM) × Core Dia (In) × π ÷ Line Line Speed (IPM)
5. Buildup Ratio: Full Coil Diameter (In) ÷ Core ID (In)
6. Pump Speed (RPM): Motor Displacement x Motor Speed ÷ Pump Displacement
7. Hydraulic Motor Pump Torque (Ft-Lb): Displacement (In^3) × Pressue (PSI) ÷ 24 π
8. Spindle Speed (RPM): Web Speed (FPM) ÷ Coil Circumference (Ft)
9. Spindle Torque (Ft-Lb): Force (LBf) × Coil radius (Ft)
10. Coil Diameter (Ft-Lb): Line Speed (FPM) ÷ Spindle Speed (FPM) × Full Coil Diameter (In)
11. Typical Closed Loop Uncoiler Circuit



Typical Closed Loop Uncoiler Circuit

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