New Coiling / Uncoiling Technology for the Steel Industry

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New Coiling / Uncoiling Technology for the Steel Industry

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

Introduction

Center winding is a common method of coiling processed steel web. Most steel coilers are powered by electric variable speed drives and motors. While web tension remains constant throughout the coiling process, the coiler motor's speed and torque change inversely proportional of one and other due to the buildup. This phenomenon demands the motor's maximum torque when the coil is full and maximum speed when at the core. The end result is that a much larger motor needs to be selected to meet these requirements. By combining a variable speed electric drive and a variable displacement hydrostatic drive, we can drastically reduce the motor size which lowers both installation costs and electrical parasitic losses. The purpose of this paper is to review the theoretical aspects of combining the best features of electrical and hydraulic systems to optimize the coiling and uncoiling process with the goal of making the technique popular among energy conscious engineers.

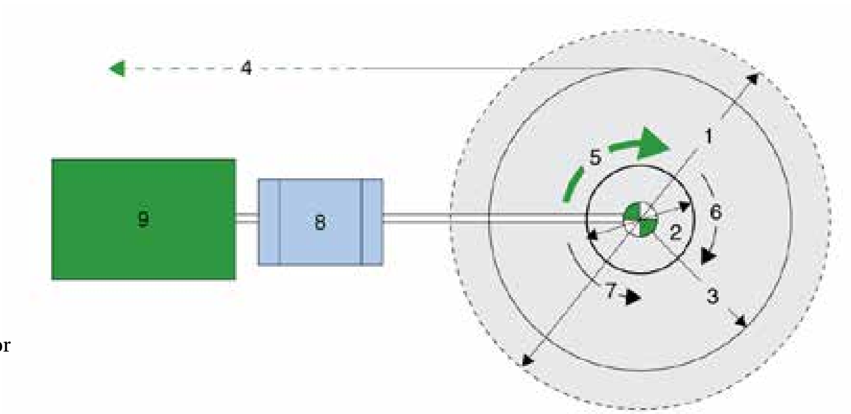
Discussion

In this document for simplicity, "coiler" refers to both the coiling and uncoiling processes, unless otherwise specified. Parameters affect the coiling process are noted in Figure 1 below.

Coiling and uncoiling is a fine balance between speed and torque. When coiling, as the roll builds, its circumference gets larger; therefore, on every rotation a greater length of material is consumed. To keep up with the flow of material, the coiler must slow down with every added layer. This build up also increases the coiling arm; therefore, to maintain tension, the coiler must increase torque proportional to the coil diameter. The example below (Figure 1) is used to help with better understanding of this process.

Figure 1: Typical Coiler / Uncoiler Critical Parameters

1. Full Coil OD[i]
2. Core / Spindle OD
3. Coiling Arm
4. Web Tension
5. Torque direction
6. Coiling rotation
7. Uncoiling rotation
8. Mechanical Gearbox
9. Variable Speed electric Motor

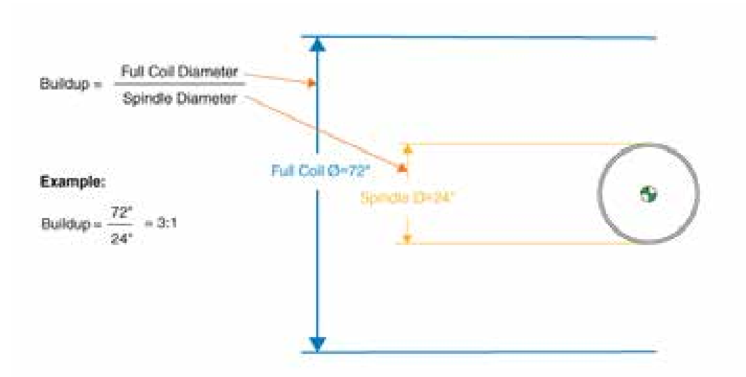


[i] Outer Diameter

Coil Buildup

Coiler buildup is the ratio of full coil diameter to its core OD or spindle OD. For example, a 72” roll with a core diameter of 24” has a 3:1 build up or in case of uncoiling, 3:1 builddown ratio. See Figure 2.

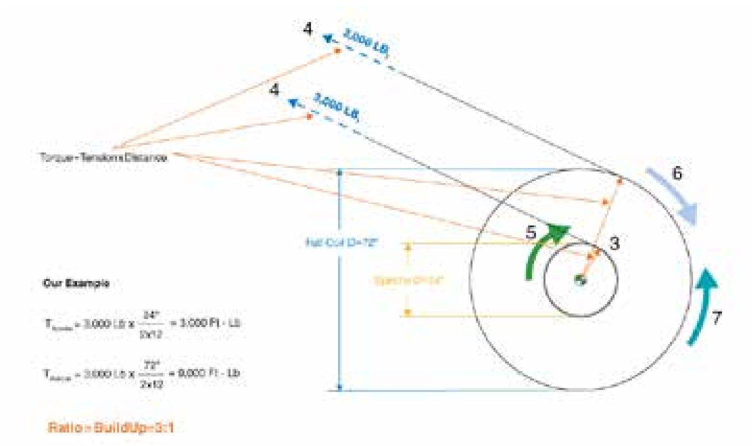
Figure 2: Coiler Buildup



Coiling Torque

To maintain tension, the coiler 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. The required torque can be calculated by multiplying the web tension by the coil radius. As the coil builds up, the required motor torque increases proportionally. In this example, a 3,000 Lb tension requires 3,000 Ft-Lb[ii] of torque at core and 9,000 Ft-Lb[iii] at full roll. See Figure 3.

Figure 3: Coiling Torque

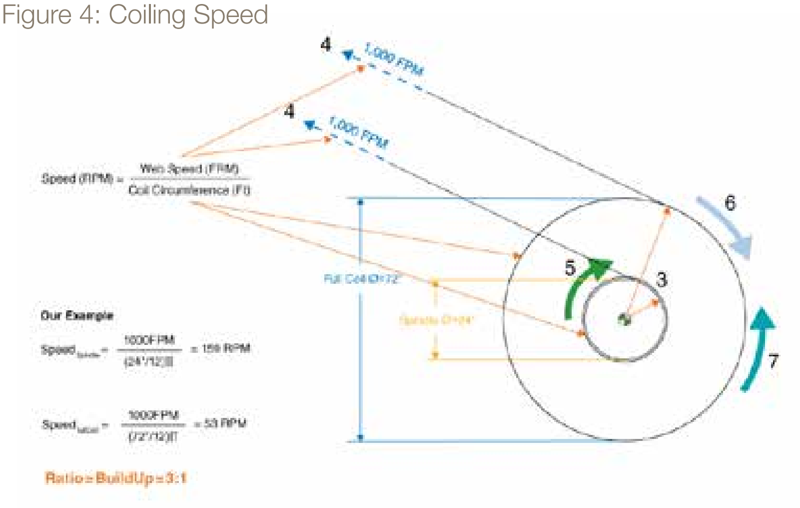


1. Full Coil OD
2. Core / Spindle OD
3. Coiling Arm
4. Web Tension
5. Torque direction
6. Coiling rotation
7. Uncoiling rotation
8. Electric Motor
9. Gearbox

Coiling Speed

To maintain tension, the coiler must keep adequate rotational speed, meaning a coil must match its surface speed to the incoming web speed at all times. The spindle speed is calculated by the line or web speed divided by the coil circumference. For a web speed of 1000 FPM, a 24” empty spindle must turn at 159 RPM[iv] as shown in Figure 4. At our 72” full roll, the spindle has to slow down by the buildup ratio to maintain the same surface speed. A full coil at same line speed spins only 53 RPM. See Figure 4.

Figure 4: Coiling Speed



1. Full Coil OD
2. Core / Spindle OD
3. Coiling Arm
4. Web Tension
5. Torque direction
6. Coiling rotation
7. Uncoiling rotation
8. Electric Motor
9. Gearbox

Coiling Power

Since web tension and line speed are constant during the buildup, the coiling power requirements remain constant and equal to the web horsepower. In the example below, a 100 HP[v] 1,800 RPM electric motor with a 11.3:1 gearbox may first appear to handle the application, since web horsepower computes to be 91HP[vi] and the 159 RPM gearbox output speed matches our full speed requirements which occur at core diameter. However, due to buildup during the process, the motor is required to reduce speed inversely proportional. Knowing that an electric motor's torque is constant from 0 to base speed and its power is directly proportional to its rotational RPM as the motor slows down due to buildup, its output power is also reduced. Therefore, when the coil reaches full diameter and the motor is running at only a third of the speed (53 RPM), the motor's maximum HP has dropped to a third, or 33HP. When the electric motor is properly sized, it turns out to be much larger since it has to produce the required max torque and max speed, though not at the same time. The computations result in a 273 HP[vii]. However, drive system engineers can lower the horsepower by using different types of electric motors; for instance, by using an eight pole 900RPM base speed motor, its size drops to 137 HP. Unfortunately, an eight pole 150 HP motor can cost as much as a 300HP standard 4 pole motor. Also, the gearbox can become more expensive due to the higher input torque requirements.

Currently, there are many aging low base speed DC electric motors in use. These motors are inefficient and no longer manufactured, but steel plant managers have learned to live with them since they are very difficult to replace or upgrade.

Motor Power [HP]	Motor Constant Torque Range	Motor Constant Speeed Range	Gearbox Ratio
137	900	1800	11.3:1
182	1200	1800	11.3:1
273	1800	1800	11.3:1

ii $Torque\ (Ft - Lb) = Force(LBf) \times distance\ (ft) = 3000 \times \frac{24"}{2 \times 12} = 3,000$

iii $Torque = 3,000 \times \frac{72"}{24} = 9,000\ or\ 3,000 \times 3:1\ Buildup$

iv $Coil\ Speed\ (RPM) = \frac{Web\ Speed\ (FPM)}{Coil\ Circumference\ (Ft)} = \frac{1000FPM}{(24"/_{12})\pi} = 159RPM$

v *For sake of simplicity efficiency and other winding losses are not considered*

vi $Web\ Power\ (HP) = \frac{Tension\ (LBf) \times Web\ Speed\ (FPM)}{33,000} = \frac{3,000 \times 1000}{33,000} = 91\ HP$

vii *See appendix for winder motor computation formulas*

Drive Controlled Pump

Hydraulic systems are great for their power density and delivery. Electric motors and variable speed drives are great for their programmability and responsiveness. For many years fluid power and drive system engineers could see the potential for combining the two technologies; however, historically, limited successes were achieved and the combined technology remained relatively unpopular. In today's manufacturing environment, the higher cost of electricity and the increasing global concern for the CO_2 footprint offer opportunities to reevaluate the combined technology. Today, the advancement in new VFD control algorithms, faster programmable variable frequency drives, and more efficient hydraulic pumps allow engineers from both technologies to work together with greater opportunities for success by implementing technology known as drive controlled pumps or DCP[viii].

> *"Advancements in VFD control algorithms, faster programmable variable frequency drives, and more efficient hydraulic pumps allow fluid power and drive system engineers to work together with greater opportunities for success by implementing drive controlled pump (DCP) technology."*
>
> — Rashid Aidun, Application Engineer, Parker Hannifin

DCP Coiling

As previously demonstrated, the traditional way uses motors many times larger than the web power. DCP takes advantage of a variable ratio hydraulic transmission to keep the motor size close to web horsepower.

In Figure 5 below, an 11.3:1 speed reduction was needed for a 273 HP standard 4 pole motor. To use DCP, we can replace the mechanical gearbox with a hydraulic pump and motor with the same displacement ratio. This produces the same speed reduction; furthermore, we can select a hydraulic motor with a variable volume to offset the buildup ratio.

Having the capability for a variable ratio allows the electric motor to run at full speed, maintaining the constant horsepower requirement. For our example, we could replace the mechanical gearbox with a 5,000 PSI hydraulic transmission. We start by using a fixed pump of 4.0 in^3/rev; next we connect it to a variable displacement motor with minimum volume of 45.2 in^3, this displacement is the result of 11.3:1 speed reduction[ix]. Maximum hydraulic motor displacement must be greater or equal to 135.7 in^3 due to the 3:1 buildup. If line runs at 1,000 FPM, the electric motor powering the fixed pump runs at 1,796 RPM[x], generating 30.8 GPM of hydraulic flow.

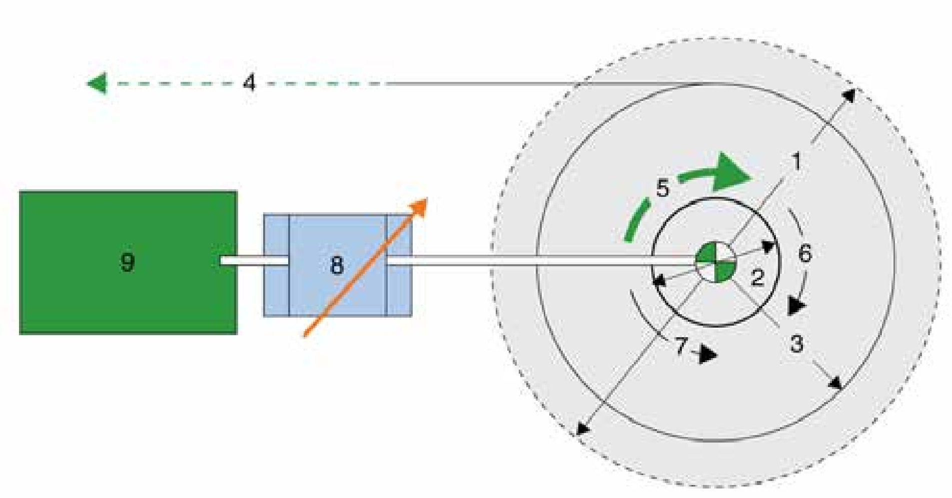
When the coiler is running at minimum diameter, the hydraulic motor is set to its minimum displacement of 45.2 in^3; this allows the hydraulic motor to run at its maximum speed of 159 RPM. In other words, when the pump runs at a smaller displacement, it produces lower torque at a higher speed. At this point, the hydraulic motor generates the minimum required torque of 3,000Ft-Lb[xi].

As the roll builds up, the DCP controller increases the motor displacement proportional to the diameter. This will slow the coiler down while increasing its torque.

At full coil, the hydraulic motor volume will reach 135.7 in^3. While the hydraulic pump flow remains constant, the hydraulic motor speed is reduced to 53 RPM and its torque reaches to 9,000 Ft-Lb.

Please note that during a line speed change, the DCP controller maintains the displacement of hydraulic motors, while changing the main pump's electric motor speed to match the desired line speed. In other words, the variable displacement hydraulic motor is used solely to manage the coil buildup, giving the pump's electric motor both the speed and torque capabilities to regulate web tension.

Figure 5: Typical Coiler / Uncoiler Critical Parameters



1. Full Coil OD
2. Core OD
3. Coiling Arm
4. Web Tension
5. Torque direction
6. Coiling rotation
7. Uncoiling rotation
8. DCP hydraulic transmission
9. Variable Speed electric Motor

[viii] *DCP is Parker technology which combine variable speed drive with fixed or variable displacement pumps*

[ix] $Minimum\ Displacement = Pump\ displacement \times Reduction\ ration = 4 x\ 11.3 = 45.2$

[x] $Pump\ Speed\ (RPM) = \frac{Motor\ displacement\ x\ Hyd\ motor\ speed}{pump\ displacement} = \frac{45.2 \times 159}{4} = 1{,}796\ RPM$

[xi] $HYD\ Motor\ Torque\ (Ft - Lb) = \frac{displacement\ In3 \times Pressue\ (PSI)}{24\pi} = \frac{45.2 \times 5{,}000}{24\pi} = 3{,}000$

DCP Controlled Coiling

Diagrams 1 and 2 below show the control schematic of DCP coiling and uncoiling system.

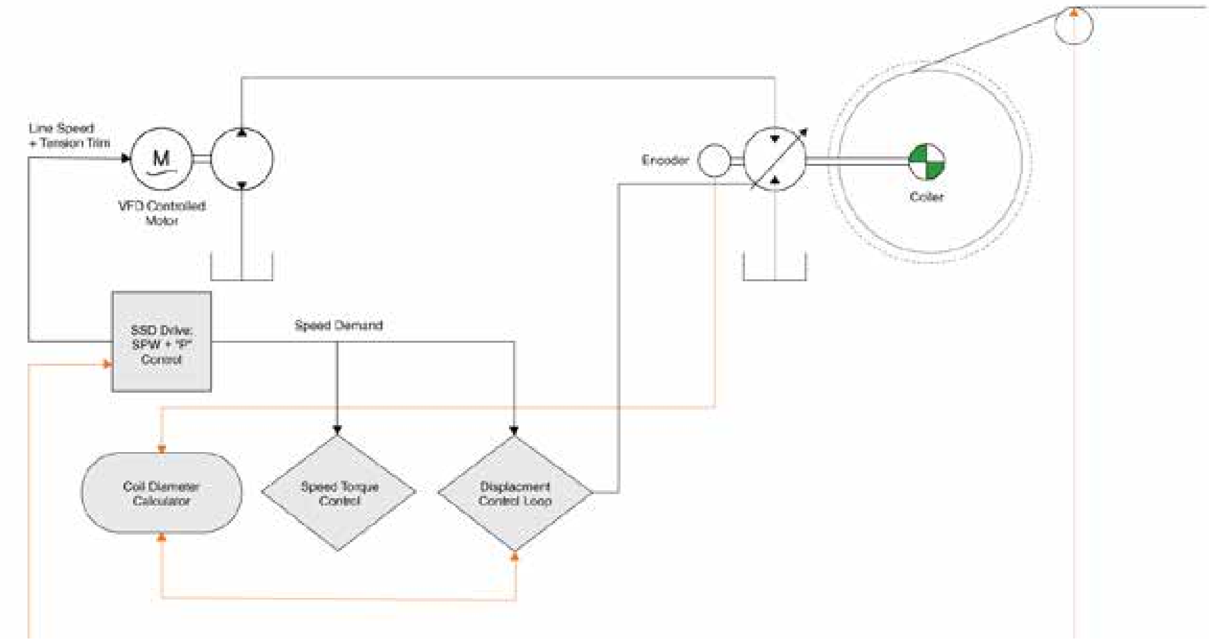


Diagram 1: Simplified DCP Coiled Circuit

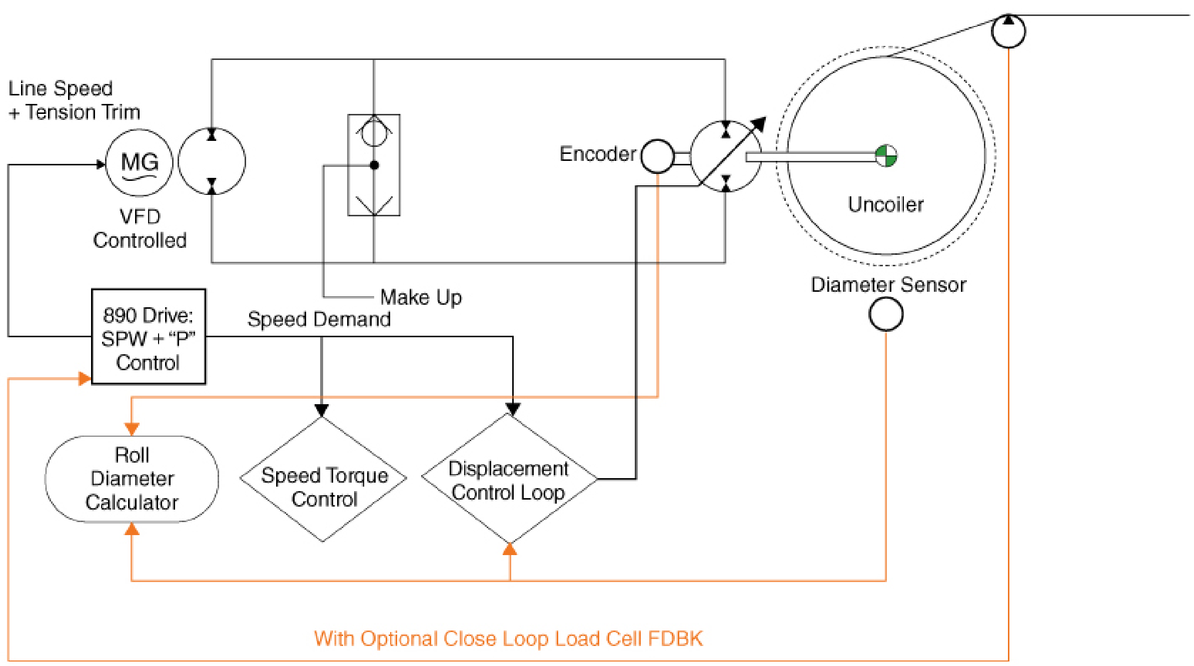


Diagram 2: Simplified DCP Uncoiled Circuit[xii]

[xii] *See reference 11 for typical closed loop Uncoiler hydraulic circuit*
[xiii] *Variable Speed Drive*

Conclusions

The advancements in hydraulics and variable speed drives were running in parallel for many years, but on the opposite sides of the fence from each other. 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[xiii] and hydraulics was difficult at first: The unforgiving nature of positive displacement pumps and the non-compressibility of the fluids, demanded a different solution than what VSD engineers had experienced with more forgiving 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 illustrates that the traditional coiling requires a 4 pole motor, and a 11.3:1 gearbox solution demands a 300 HP electric motor which is operated by a 300HP heavy duty rated VFD, while web tensioning only required a 91 HP. If the coil buildup was 5:1 instead of 3:1, a 500HP motor was needed. This phenomenon becomes more pronounced in finishing and slitting lines where coil buildup is quite high. Using DCP technology, as described in this paper, keeps the electric motor and VFD size down to web horsepower, reducing costs of both the electric and drive system and installation. Since DCP technology does not use flow reducing valves in the 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 effective and easier to maintain.

Taking advantage of electric drive and hydraulic technology yields a positive outcome in coiling and uncoiling technique. The 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, and they operate at much lower noise and temperatures resulting in quieter and cooler surroundings.

> *"DCP hydraulic systems are less complex and more efficient than traditional hydraulic systems. They operate at much lower noise and temperatures resulting in quieter and cooler surroundings."*
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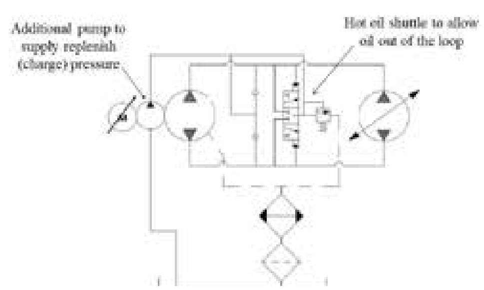
> — Rashid Aidun, Application Engineer, Parker Hannifin

References

1. $Linear\ Web\ Power(HP) = \frac{Tension\ (LBf) \times Web\ Speed\ (FPM)}{33{,}000}$
2. $Torque\ (Ft - Lb) = \frac{Power\ (HP) \times 5252}{Rotational\ Speed\ (RPM)}$
3. $Acceleration\ Torque\ (Ft - Lb) = \frac{Coil\ Inertia\ (Lb - Ft^2) \times Speed\ Change\ (RPM)}{308 \times Acceleration\ time\ (Sec)}$
4. $Coiler\ Gearbox\ Ratio = \frac{Motor\ Max\ Speed\ (RPM) \times Core\ Dia\ (in) \times \pi}{Line\ Line\ Speed\ (IPM)}$
5. $Buildup\ Ratio = \frac{Full\ Coil\ Diameter\ (in)}{Core\ ID(in)}$
6. $Pump\ Speed\ (RPM) = \frac{Motor\ displacement\ x\ motor\ speed}{pump\ displacement}$
7. $HYD\ Motor - Pump\ Torque\ (Ft - Lb) = \frac{displacement\ In3 \times Pressue\ (PSI)}{24\pi}$
8. $Spindle\ Speed\ (RPM) = \frac{Web\ Speed\ (FPM)}{Coil\ Circumference\ (Ft)}$
9. $Spindle\ Torque\ (Ft - Lb) = Force(LBf) \times Coil\ radius\ (ft)$
10. $Coil\ Diameter\ (Ft - Lb) = \frac{Line\ Speed\ (FPM)}{Spindle\ Speed\ (FPM)} \times Full\ Coil\ Dia(in)$
11. *Typical Closed loop Uncoiler circuit*



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