Dragload analysis: a unique method of improving paper machine efficiency

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ABSTRACT: Dragload is the force required to drive a forming fabric while the sheet is being dewatered. The suggested method for calculating dragload and component dragload uses the relationship between fabric velocity and tension and the mechanical properties of the fabric. The advantage of this method over more conventional methods is its ability to be used on any type of machine or drive system and, most importantly, its ability to localize specific areas of dragload (component dragload) without the need to interrupt production on the machine. The method's limitation is that it does not produce an exact result, only an approximation. Obtaining the exact fabric velocity is difficult; however, there is enough accuracy in the readings with which to diagnose and troubleshoot. Steps taken to reduce dragload will help decrease energy consumption and increase forming fabric life. The suggested method provides a readily visible means of determining areas of high dragload. If used, this method will provide a valuable tool for further cost improvement in the papermaking process.

KEYWORDS: Analysis, driving, efficiency, energy consumption, force, forming fabrics, friction, paper machines, papermaking equipment, runnability, trouble shooting, water removal

Dragload

Several articles have addressed the subject of dragload and serve as excellent references to understanding the important fundamentals. Specific publications have been listed at the end of this article *(1–3)*.

Dragload is defined as the force required to drive a forming fabric as the sheet is dewatering. Dragload can be characterized as a "tension drop" in a forming fabric between the maximum tension, which is usually located ahead of the couch roll, and the minimum tension, which is usually located after the wire turning roll. A similar tension drop may be experienced ahead of, and after, any single-powered roll. Dragload is a product of friction generated by the multiple components, both moving and stationary, on the fourdrinier.

Friction may also be a function of vacuum-assisted drainage elements, freeness values, basis weight, cover materials of drainage elements and fabric design. An increase in friction will result in an increase in dragload. As dragload increases, the energy consumption or torque of the powered rolls increases and the potential for wear on the forming fabric also increases.

The point at which fabric stalling occurs represents a unique situation in dragload. Fabric stalling is a result of the cumulative frictional forces overcoming the drive capability of the powered rolls *(4)*.

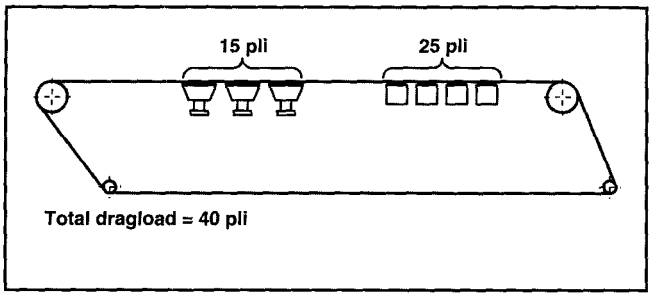
Dragload is cumulative. A typical calculated value represents the sum total of *all* the frictional components on the machine. This approach can be used to formulate an energy balance profile of the machine. If the total dragload is 40 pli, various frictional components will utilize different percentages of the total 40 pli (see **Fig. 1**). Past methods to determine these sectional energy consumptions were impractical and usually involved breaking the sheet and running it into the couch pit. The method suggested here makes these figures readily available without any interruption in the papermaking process.

Dragload equation (conventional)

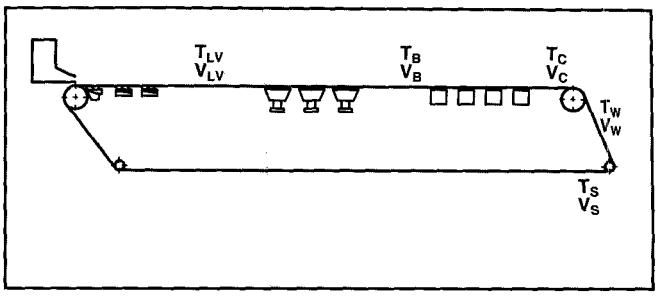
The conventional dragload equation relates electrical data to dragload by the following:

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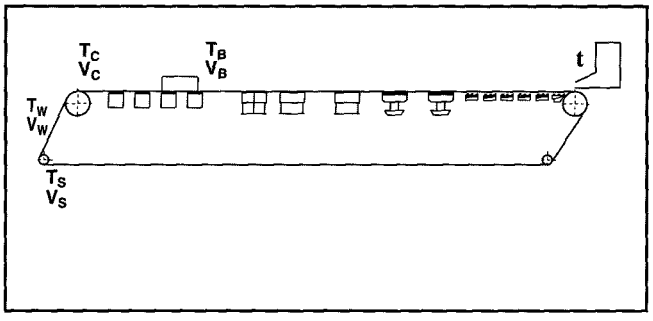
1. Dragload is cumulative



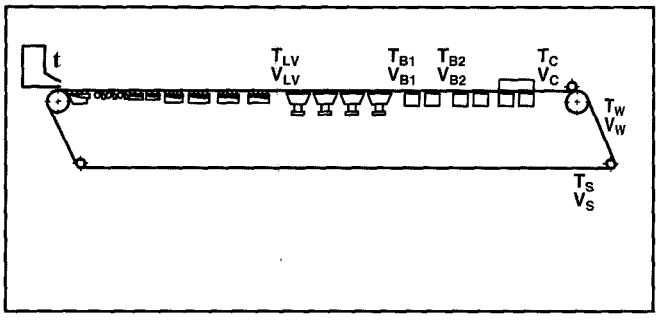
2. Fabric velocity and tension changes occurring on a typical paper machine: $T_S<T_{LV}<T_B<T_C$ due to friction (energy consumption); $n_S<v_{LV}<v_B<v_C$ due to friction (energy consumption); $T_C>T_w>T_S$ due to powered rolls (energy contribution); and $v_C>v_W>v_S$due to powered rolls (energy contribution)



3. Data locations (Available data: $v_S, v_W, v_C, v_B, T_S, t$; calculated data: T_W, T_C, T_B)



4. Data points analyzed for dragload study (Available data: $v_S, v_W, v_C, v_{B2}, v_{B1}, v_{LV}, T_S, t$; calculated data: $T_W, T_C, T_{B2}, T_{B1}, T_{LV}$)



$$DL = (V \cdot A)/(v \cdot S \cdot 22.6 \cdot 10^{-3}) \cdot 0.8 \quad (1)$$

where

DL = dragload, pli

V = drive volts, V

A = drive amps, A

v = nominal fabric speed, ft/min

S = nominal fabric width, in.

The constant, 22.6×10^{-3}, represents a unit conversion and 0.8 represents a mechanical loss multiplier.

This equation is useful only if the total dragload of the machine is desired. It is impractical to be used to determine component dragload energy consumption. If the drive rolls are not electrically driven, this equation will not be applicable.

Dragload—component dragload method

The component dragload method uses the relationship between the mechanical properties of the fabric and the associated velocities of the fabric over stationary and moving components. A preliminary equation can be developed which will lead to this type of dragload determination *(5)*. The relationship can be shown as follows:

$$T_n = (v_n/v_s)(EM + T_s) - EM \quad (2)$$

where

T_n = calculated fabric tension, pli

v_n = fabric speed at point n, ft/min

v_s = fabric speed on the slack side, point s, ft/min

T_s = slack side tension, pli

EM = fabric elastic (Young's) modulus.

As the fabric is subjected to frictional components, i.e., stationary drainage components, tension continually increases. As the tension increases, the fabric becomes narrower and travels at higher velocity. Conversely, as energy is being imparted to the fabric by the drive rolls (usually the couch and/or wire turning roll), the tension reduces and the fabric widens out and travels at a slower velocity. The point of maximum fabric tension and velocity is just ahead of the first drive roll (usually the couch), while the point of minimum tension and velocity is just after the last drive roll (usually the wire turning roll) (**Fig. 2**). The actual fabric tension at any point along the fabric loop is a function of fabric velocities (v_s, v_n) and the fabric's elastic modulus (EM). EM is a stress/strain relationship that is usually tested by the fabric supplier. EM represents the amount a fabric stretches at a given tension.

As previously discussed, dragload is the tension drop the fabric undergoes as it travels over stationary and moving components. As a result, Eq. 2 can be restated in a simpler form. Since:

$$DL = T_n - T_s \quad (3)$$

Substituting Eq. 2 for T_n produces:

I. Energy contributed by the drive rolls

Location	Dragload, pli	Horsepower	Load share, %
Couch roll	2.5	38	12
Wire turning roll	17.8	267	88
Total	20.3	305	100

II. Energy consumed by the stationary drainage elements

Location	Dragload, pli	Horsepower	Consumed, %
Over suction boxes	14.6	219	71
Lovacs and rolls	5.7	86	29
Total	20.3	305	100

$$DL = (v_n/v_s)(EM + T_s) - EM - T_s \quad (4)$$

which simplifies to:

$$DL = (v_n/v_s - 1)(EM + T_s) \quad (5)$$

where

DL = component dragload.

Thus, dragload can be calculated at any point along the fabric loop by obtaining the tension at point s (T_s), velocity at point s (v_s) and velocity at point n (v_n). The only tools needed are a fabric tensiometer and an accurate tachometer.

Relationship of *EM* to temperature

Since the *EM* of a forming fabric is dependent on temperature, Eq. 5 can be made even more accurate by incorporating this dependency *(6)*. The mechanical strength of forming fabrics, which use polyester strand material, drops as the temperature increases. In the temperature region of most paper machines (headbox temperatures in the range of 110°F to 150°F), the relationship between elastic modulus and temperature can be considered linear. Consistently, the relationship between temperature and elastic modulus is as follows:

$$EM_t = EM_r - Kt \quad (6)$$

where

EM_t = elastic modulus at temperature t, pli

EM_r = elastic modulus at reference temperature r, pli

t = running temperature of fabric, °F

K = modulus/temperature response constant, pli/°F.

In some cases, it is useful to take the temperature at each point where the speed of the fabric is being measured. However, in most instances, this is not necessary because of the strong dependency of fabric velocities in the dragload equation.

The effect of temperature may be incorporated into the dragload equation as follows:

$$DL = (v_n/v_s - 1)(EM_r - Kt + T_s) \quad (7)$$

or,

$$DL = (v_n/v_s - 1)(EM_t + T_s) \quad (8)$$

In this form, a good estimate of dragload, at any point along the fabric loop, can be made with readily available data.

Case studies

Case 1: A kraft bag/lightweight linerboard machine with fabric stalling difficulties

The machine was experiencing stalling problems after a 10% increase in speed. The speed increase had been accomplished primarily with a gearbox change to the wire turning roll. The machine was turbine driven; therefore, little knowledge of the couch/wire turning roll load share was available. The dragload was determined to see what might be causing the fabric stalling problem.

Machine data:

- Grade = 78-lb kraft bag
- Headbox temperature (t) = 135°F
- Slack-side fabric tension (T_s) = 19.0 pli

Pertinent fabric velocities:
(See **Fig. 3.**)

- Slack side (v_s) = 1994.5 ft/min
- Between couch and wire turning roll (ahead of wire turning roll)(v_w) = 1999.5 ft/min
- Ahead of couch roll (v_c) = 2000.2 ft/min
- Ahead of first suction box (v_b) = 1996.0 ft/min
- Effective elastic modulus at the headbox temperature (EM_t) = 7100 pli.

Calculation of dragloads

Dragload over wire turning roll (DL_w)

$$DL_w = (v_w/v_s - 1)(EM_t + T_s)$$

$$DL_w = (1999.5/1994.5 - 1)(7100 + 19)$$

$$= 17.8 \text{ pli}$$

$$T_w = DL_w + T_s$$

$$= 17.8 + 19.0 = 36.8 \text{ pli}$$

Dragload over couch (DL_c)

$$DL_c = (v_c/v_w - 1)(EM + T_w)$$

$$= (2000.2/1999.5 - 1)(7100 + 36.8)$$

$$= 2.5 \text{ pli}$$

$$T_c = DL_c + T_w$$

$$= 2.5 + 36.8 = 39.3 \text{ pli}$$

Dragload over the suction boxes (DL_b)

$$DL_b = (v_b/v_c - 1)(EM + T_c)$$

$$= (1996.0/2000.2 - 1)(7100 + 39.3)$$

$= -14.6$ pli (the negative number represents energy consumed by a frictional component)

$$T_b = DL_b + T_c$$

$$= -14.6 + 39.3 = 24.7 \text{ pli}$$

Note: when a result is positive, i.e., + x pli or + y hp, the (+) sign represents energy contribution, e.g., a couch roll, wire turning roll. When a result is negative, the (–) sign represents energy-consumed by some type of frictional component, (e.g., suction boxes, low vacuum units). For brevity, when a result is positive, the (+) sign will be omitted.

Conversion of dragload to horsepower

Dragload is directly proportional to horsepower and can be converted to horsepower using the following equation:

$$hp = DL \cdot v \cdot s/33{,}000$$

where

hp = the dragload converted to horsepower

DL = the component dragload, pli

v = the average fabric speed, ft/min

s = the average fabric width, in. and 33,000 is a unit conversion (33,000 ft-lb/min = 1 hp).

Horsepower contributed by the wire turning roll (hp_w) equals:

$$hp_w = DL_w vs/33{,}000$$

$$= (17.8)(1998)(248)/33{,}000$$

= 267 horsepower contributed by the wire turning roll

Horsepower contributed by the couch roll (hp_c)

$$hp_c = DL_c vs/33{,}000$$

$$= (2.5)(1998)(248)/33{,}000$$

= 38 horsepower contributed by the couch

An interesting calculation is the horsepower being consumed by the suction boxes (hp_s).

$$hp_B = DL_B vs/33{,}000$$

$$=(-14.6)(1998)(248)/33{,}000$$

=-219 hp consumed by the suction boxes.

Tables I and II are energy balance sheets: one for the drive rolls (energy contributed) and one for the frictional components (energy consumed).

By reviewing the percent load share column of Table I, one immediate problem becomes clear. At the time of the speed increase, the size of the couch helper drive motor was not correctly calculated. The result was an insufficient energy contribution from the couch and an energy over-contribution from the wire turning roll. Increasing the size of the couch helper drive motor balanced out the energy contribution from both couch and wire turning roll, and thus solved the slippage problem. Further analysis showed that the slack side forming fabric tension of 19 pli was too low. Increasing the fabric tension to 25 pli temporarily reduced the stalling problem.

It can also be seen from the energy balance sheet in Table II that the percentage of energy consumed by the suction boxes was too high. Proper scheduling of the suction box vacuums would still allow acceptable dewatering, while reducing the total dragload of the machine. As a general rule, the suction boxes should consume no more than about 55% of the total dragload on conventional fourdriniers. [Note: the remaining components of the fourdrinier consumed 86 hp (267 + 38 – 219).]

This is an approximation of the load share around the fourdrinier. Although further analysis could localize the consumption of energy resulting from the low-vacuum section and foil units, these data were not needed to solve the stalling problem.

III. Power contribution from drive rolls

Location	Dragload, pli	Horsepower	Load share, %
Couch roll	11.2	152	45
Wire turning roll	14.0	190	55
Total	25.2	342	100

IV. Power consumption by the stationary drainage elements

Location	Dragload, pli	Horsepower	Consumption, %
Foil units	0.4	5	1
Lovacs	10.8	147	43
Suction boxes 1–2	3.2	44	13
Suction boxes 3–6	10.8	147	43
Total	25.2	343	100

V. Combined drainage and dragload analysis

Location, ingoing and outgoing	*Upstream and downstream consistencies, %*	*White water drained, gal/min/in.*	*Energy consumption, %*
Forming board to last foil unit	0.85–2.26	42.4	1
First Lovac to last Lovac	2.26–7.85	14.6	43
First suction box to last suction box	7.85–16.34	2.9	13
Third suction box to last (6th) suction box	16.34–17.97	0.2	43
Total	0.85–19.97	60.1	100

Case 2: component dragload study on a corrugating medium machine

A routine drainage analysis was performed on a corrugating medium machine. A component dragload study was done as part of the drainage analysis, in an attempt to resolve a fabric life problem.

Only the available data and calculated results will be presented here since the mechanics of the component dragload calculations were presented in Case 1 above. **Figure 4** shows the points at which data for the study were taken.

Available data:

- Grade = 26 lb corrugated medium
- Headbox temperature (t) = 155°F
- Effective EM (EM_t) = 7300 pli
- Slack side tension (T_s) = 30 pli

Velocities:

- Slack side (v_s) = 1627.3 ft/min
- Ahead of wire turning roll (v_w) = 1630.4 ft/min
- Ahead of couch (v_c) = 1632.9 ft/min
- Ahead of 3rd suction box (v_{B3}) = 1630.5 ft/min
- Ahead of 1st suction box (v_{B1}) = 1629.8 ft/min
- Ahead of 1st Lovac (v_{1v}) = 1627.4 ft/min

Results

Looking at **Table III**, one sees no evident problem since the percentage of load share between the couch and the wire turning roll is well within the normal range of energy contribution. In **Table IV**, the energy consumed by the stationary elements also appears to be in the normal range. However, if the total suction box energy consumption in Table IV is calculated, the resulting energy consumption percentage is slightly above the 55% rule of thumb stated above (13 + 43 = 56%). This fact alone was not enough to indicate a problem.

The combined drainage and dragload data in **Table V** tells the story, however. It can be seen from the data that the last four suction boxes were not contributing significantly to sheet dewatering (16.34–17.97% consistency or 0.2 gal·min/in. water removed). It should also be noted that these four boxes were consuming 43% of the total energy needs of the machine. The solution to the problem, in this case, was more efficient use of the high vacuum drainage equipment. The recommendation was to turn off one suction box, which had no detrimental effect on drainage and resulted in a 10% load reduction. The utilization of proper water management techniques resulted in a 20% load reduction. In total, the load reductions not only reduced the energy consumption on the machine, but had a significant positive impact on fabric life.

The combination of dragload and drainage analyses give a clear picture of energy imbalances on the paper machine (Table V).

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