LATEST TECHNOLOGY IN FLEXIBLE ROLL BALANCING

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ABSTRACT

In today's economy, the paper industry must increase the speed of its paper machines for greater profit. Paper machines built in the early 70's are now exceeding their initial designed speed, in some cases by nearly 50%. Not surprisingly, paper machines and more specifically the flexible rolls are showing signs of fatigue leading to potential catastrophic failures.

Unable to increase roll diameter due to the cost involved to modify adjacent pieces of equipment, roll speed is now exceeding 85% of critical speed which is considered as an extreme limit when designing a new roll.

This problematic forced the roll manufacturers to develop new manufacturing techniques and quality standards to improve the stability of a flexible roll at higher speed.

INTRODUCTION

Paper machine and roll builders have been manufacturing flexible rolls with a margin for future speed increase. Typically, designed speed does not exceed 70-75% of the first mode natural frequency (also called critical speed). For machines operating over a wide range of speed, roll builders are also taking into account the half critical speed in their calculations.

As an example, most of the rolls on a winder are designed to operate below the half critical speed to avoid development of vibration during the acceleration/deceleration cycles. Other rolls, such as paper rolls, can also be designed to operate below the half critical speed since they are not wrapped in a felt to damp the vibration amplitude. Paper machines producing a wide range of basis weights are engineered to operate in a safe zone between half critical and critical speed when possible.

Because the speed of paper machines is now exceeding the initial designed speed, any of above design criteria when designing a replacement roll becomes obsolete and new quality standards and manufacturing techniques are mandatory to reduce vibration amplitudes to acceptable levels

CASE STUDIES

To endorse above problematic, here are two recent case studies where the existing flexible rolls are replaced to increase paper machine speed or to simply avoid disastrous failures due to excessive forces induced in the roll body or nearby framing.

MILL A - Because of space limitation, new replacement rolls outside diameter cannot be increased and must operate between 45% and 85% of the critical speed.

MILL B - For similar reason, new replacement rolls must operate at speeds reaching 90% of the critical speed. The initial and impracticable demand from the mill was even 100% of the critical speed.

SOURCES OF VIBRATION

There are many causes for a flexible roll to develop vibrations on a paper machine. Among them:

1. Residual unbalance
2. Total dynamic run out
3. Operation at or near 50% of critical speed
4. Speeds exceeding 80%-90% of critical speed
5. Roll speed matching paper machine structure natural frequency

Any of these causes can be observed independently or in combination. Before replacing or repairing a roll, the engineer must have a good understanding of what might cause these vibrations.

RESIDUAL UNBALANCE

Looking at a balancing correction plane intersecting the rotation axis of the roll, the residual unbalance can be seen as a mass with a center of gravity turning around the rotation axis of the roll (Fig1).

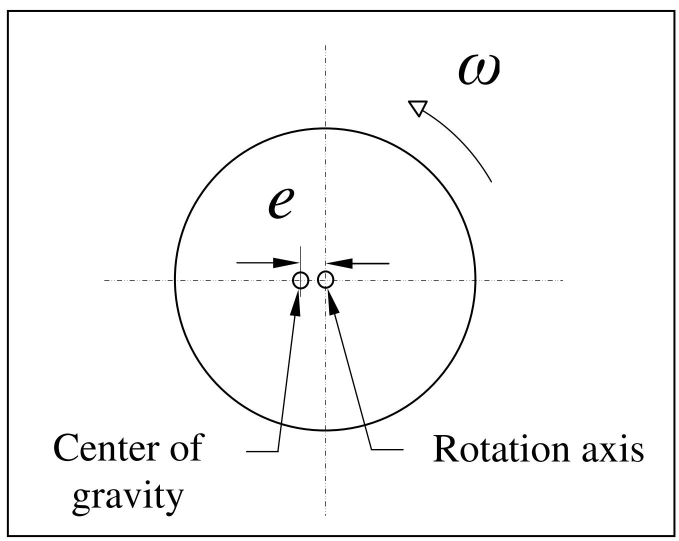


Fig 1 Definition of unbalance in a plane

ISO1940/1 international standard is widely used in pulp & paper industry to specify the quality grade required on a roll. The quality grade is expressed in mm/sec (G1.0 = 1 mm/sec, etc…). The residual unbalance (U_{per}) per side is expressed in (g-in/lb). The permissible residual unbalance is proportional to the quality grade (G) used and is inversely proportional to the rotational speed. The tendency over the years has been to lower the permissible unbalance. While G1.6 and G2.5 was used in the past, G1.0 is now the norm

$$G = \omega e = 2\pi n e$$

$$m_{perm} = \frac{me}{2r} = \frac{Gm}{4\pi n r}$$

Where,
m= roll mass
n= Revolutions per minute
r = Counterweight radius

Fig 2 Permissible unbalance per side

used in the industry for flexible rolls.

Equations in Figure 2 give you the relation between the permissible unbalance weight, roll mass, quality grade, RPM and counterweight mounting radius.

TOTAL DYNAMIC RUN OUT

Even if a roll is perfectly balanced, the surface of the shell might deform and cause vibration when the roll is in contact with another piece of equipment such as a doctor, a felt or another roll.

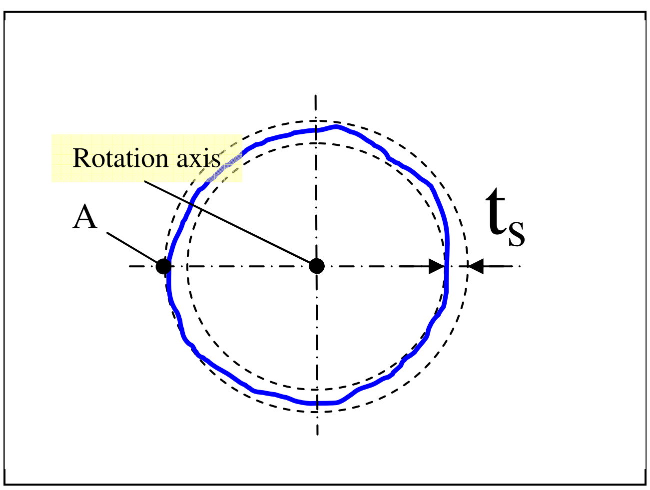


Fig. 3 Graphical representation of a static run out

The total dynamic run out is composed of the static run out, the shell deformation and the whip.

The static run out (Fig. 3) is a measurement done while the roll is slowly rotating around its axis. It comes from a permanent out-of-round of the shell in a specific plane and/or a permanent curvature of the roll body due to stresses induced by machining tool on the surface.

The dynamic run out is the measurement taken when the roll is turning at its operating or designed speed. This measurement combines:

1. The static run out
2. The shell deformation due to centrifugal force, uneven wall thickness and counterweight bolted to the shell
3. The Whip (steady deformation of the body of a roll because the center of gravity does not coincide with the axis of rotation)

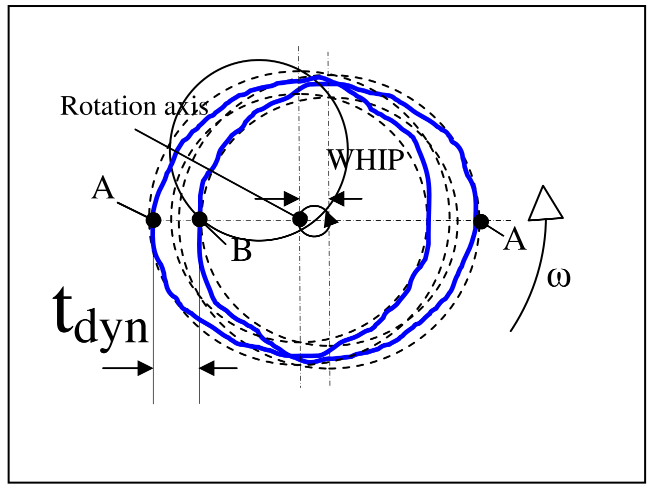


Fig. 4 Graphical representation of a total dynamic run out

Because a roll can become a source of excitation to adjacent pieces of equipment, it is important to obtain from the roll manufacturer some recommendations as far as what is the maximum acceptable static and dynamic run out for a particular application. Depending on the position of the roll on a paper those values may vary.

In the industry, an acceptable static run out can vary between 0.001inch and 0.004 inch. A total dynamic run out can vary between 0.002 inch and 0.008 inch. Generally speaking, nip rolls have more severe criteria since the vibration is directly transmitted to the rest of the machine.

HALF CRITICAL SPEED

The half critical speed does not coincide with any of the natural frequencies of a roll and is present when a roll has a relatively thin shell. Heavy rolls do not have any vibration peaks at 50% of the critical speed and do not require any weight correction at the center. The increase of the vibration at that speed comes from a certain source of excitation.

To explain this source of excitation, let's rotate a shell at relatively high speed (5,000 FPM or 750 RPM). Assume that a 50 pounds counterweight is bolted at the center of the shell. This counterweight is added because the wall thickness of the shell is not uniform. For this study, the variation in wall thickness is represented by another equivalent weight located on the opposite side of the shell (Fig.5). The shell is 24 inches in diameter with a ¾ inch average wall thickness.

At 2000 FPM, the force developed by the counterweight inside the shell is 3,600 pounds, but at 5000 FPM, the force exceeds 22,000 pounds. Consequently high detrimental stress is developed near the counterweight area and the initial cylindrical shape of the shell deforms into an elliptic shape.

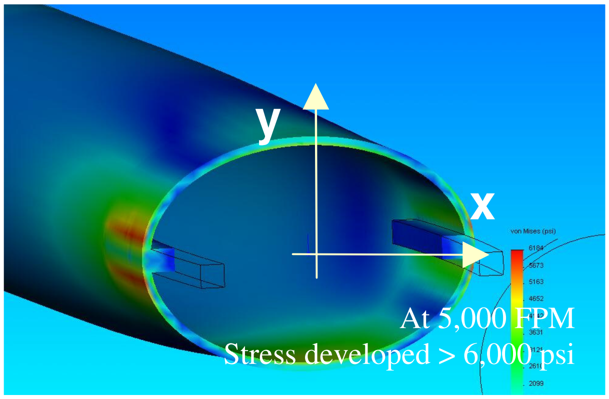


Fig. 5 Stress and deformation of a shell due to centrifugal force and excessive counterweights

When a constant force is applied such as gravitation or a felt under tension wrapping the roll, the deflection of the roll varies at a frequency equivalent to two(2) cycles per revolution (deflection is inversely proportional to the inertia of the section)

When a roll is rotating at 50% of the critical speed, this source of excitation has a frequency equivalent to the critical speed causing high amplitude vibrations.

$$\frac{1}{2} Vcr \times 2 \frac{Cycles}{Rev} = Vcr$$

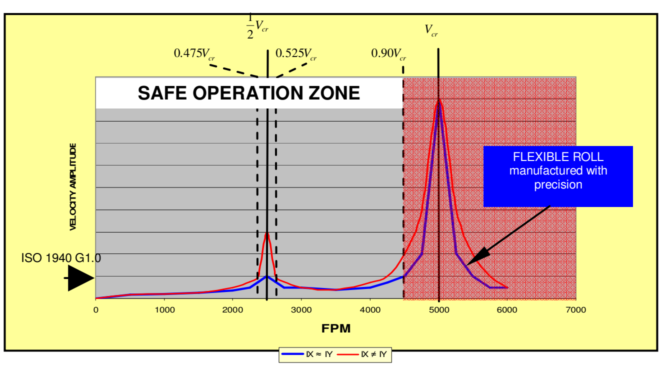


Fig. 6 Velocity amplitude vs speed

As a result, a roll with a high variation in wall thickness and consequently, having a relatively heavy counterweight will develop high amplitudes when operating near 50% of the critical speed. The shop s experience also demonstrates that it becomes more difficult to maintain an acceptable level of vibration at speeds exceeding 80% of the critical speed.

Therefore, it is very important for a roll manufacturer to machine the shell with precision to minimize the variation of the wall thickness in the centre portion of the shell and by doing so, minimize the quantity of counterweight required.

This action allows the roll, not only to operate through the half critical zone smoothly without transmitting damaging forces to the structure supporting it, but by doing so, minimizes the development of stresses detrimental to the shell due to additional centrifugal forces present when a roll operate at high rotational speed.

It is important to mention at this point that the reduction of counterweight should not prove detriment to whip reduction which is also an important source of vibration.

STRESS AND DEFORMATION

A counterweight inside a shell develops a force (F) represented by the following formula:

$$F = ma = \frac{mv^2}{r} = \frac{wv^2}{gr} = \frac{w\pi^2 N^2 r}{900g}$$

Where N = revolution per minute

The force increases considerably at higher speed and results in additional ring stress and shell deformation.

Using this formula, a fifty (50) pounds counterweight represents a 10,000 pounds (five tons) force against the shell at 5000 FPM while the same counterweight at 2500 FPM develops only 2,300 pounds force.

In addition, if a counterweight is located at the center of the roll and is bolted directly to the shell, a stress concentration factor (K_t) must be added when calculating the alternating bending stress in the shell. We do so by using the following formula:

$$\sigma_{max\,bending} = K_t \times \frac{Mc}{I}$$

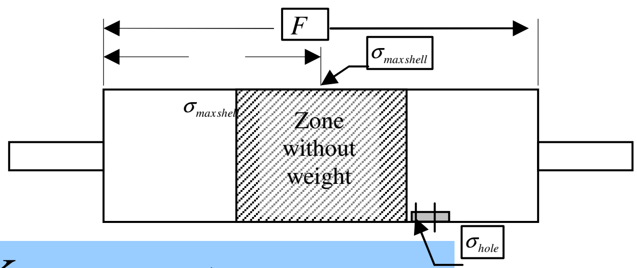
The stress concentration factor generally varies between 2.8 and 3 for a typical roll.

For all those reasons, it is not recommended to install counterweights in the center because alternating bending stress is at its highest at that point and the drilling of holes nearly triple the level of stress. Knowing that most of the roll manufacturers design shell stiffness with a safety factor of 4, the addition of a stress concentration factor to the equation reduces dangerously the original safety factor used.

In the seventies, roll manufacturers were installing counterweights at the so called “quarter points”. The main idea behind this procedure was to install the weights along the shell where the calculated bending stress multiplied by the stress concentration factor was less than the maximum calculated stress in the middle (Fig.7).

The draw back with this method is that the total quantity of weight required increases. But, individually, the weight at each of the quarter points, will be generally less (≈75%) than a single weight in the middle, which is an improvement.

This “quarter points” balancing method is still used for rolls on small and low speed machines and with rolls too small in diameter to use other methods.



$$K_t \sigma_{hole} < \sigma_{max\ shell}$$

Kt – Stress concentration factor

Fig.7 Quarter points balancing method

Nevertheless, in no circumstances should a balancing machine operator ever add a bolted weight in the middle of a roll considering the fact that the alternating bending stress nearly triples and there is a risk of shell failure due to fatigue.

WHY AND WHEN CONSIDERING INVESTING IN A FLEXIBLE ROLL MACHINED WITH PRECISION

Producing a flexible roll with precision requires additional steps in the manufacturing procedure. The additional costs are not always justified.

Here are the main reasons why or when you should consider investing this additional cost:

1. Paper machine operating over a wide range of speed such as fine paper machine producing various basis weights. Generally speaking, those machines can operate anywhere between 40% and 85-90% of the critical speed
2. Paper machine operating at or near the half critical speed of the flexible rolls; such as wide liner board machine originally design for speeds up to 2500 FPM that operates or will eventually operate at higher speed close to the half critical speed.
3. Newsprint Paper machine operating at speeds exceeding original design speed and exceeding 85% of the critical speed.
4. Paper machine experiencing excessive vibrations affecting: paper quality, felt life, framing integrity, roll integrity and/or bearing life
5. Existing rolls having bolted weights at the center of the shell and having a risk of premature failure or paper mills with a history of roll failures due to fatigue.

CONCLUSION (OR RECOMMENDATIONS)

As a maintenance manager, project manager or purchasing manager, you will probably be involved in selecting a roll manufacturer and have to compare the quality of the roll proposed.

Here is the information you should ask for in order to judge the quality of the roll offered:

Balancing quality grade

This is the level of unbalance of the roll and is expressed in mm/sec. Todays accepted norm is G1.0 for flexible rolls. A roll can be within that norm at the required balancing speed, but can exceed that norm at a different speed. If your machine operates at different speed, a balancing check over a speed range is mandatory to ensure that the balancing grade is met at all time. A roll manufactured with precision maintains its balancing grade because the shell is not distorted by centrifugal forces.

Maximum total dynamic run-out

The total dynamic run out is a value as important as the balancing grade. It combines the static run out and the dynamic run out (also called whip). Excessive run out is normally an indication of excessive wall thickness variation in the central portion of the shell or is an indication of rotation of the center of gravity (of the central portion of the shell) around the rotation axis of the roll.

The dynamic run out can be easily controlled by adding counterweights inside the shell. Yet, a small total dynamic run out does not guarantee an accurate roll.

It is also a good practice to request that a total dynamic run out reading be taken over the paper machine operating speed range.

It is preferable to add a small counterweight inside the shell to control the whip than to aim for “zero” counterweight in the center and have a high level of whip. A roll with a small dynamic run-out will run more smoothly when wrapped in a felt.

Total amount of counterweight (as % of roll weight)

This figure is the summation of all the counterweights installed on the roll in three (3) or four (4) planes (front head, shell and rear head). One (1) percent of roll weight is the maximum counterweight generally accepted.

Even if this value is an indication of the quality of a roll, it can be misleading. A roll with most of the counterweights attached to the heads and very little counterweight in the center, will behave more smoothly on the machine than the opposite. The reason is that only the counterweights attached to the shell can cause deformation of the roll. We saw earlier that deformation of the shell is detrimental to the stability of the roll passing through the half critical speed zone or when approaching the critical speed.

Maximum counterweight inside the shell

A roll having no counterweight or small counterweight inside the shell (less than 0.2% of total roll weight) will be very stable over a wide range of speed including half critical speed (0 to 90% of critical speed).

Counterweights position and Weight attachment method

Counterweights can be bolted to the shell at the “quarter points” or can be attached to an apparatus in the middle of the roll. When possible, or for wide paper machine exceeding

3000 FPM in speed, we recommend that you select the method using a counterweight attached to an apparatus mounted inside the shell.

Balancing service center

Over the years, the roll may require rebalancing due to maintenance such as journal repair or recovering.

Make sure that the rebalancing can be performed in your own or selected local service shop.

Counterweight accessibility

If ever the roll needs some adjustment after recovering or journal repair, do we have access to the counterweights in place to increase or decrease their weight?

If counterweights are not accessible, you will have no other choice but to add weight (and maybe add bolted weights) every time you rebalance. By doing so, you reduce the performance of the roll over the years.