PRACTICAL APPLICATION OF IDLER ROLLER PERFORMANCE MEASUREMENTS AND MODELS

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ABSTRACT

Idler rollers are present in abundance on most web processing lines. Their simple design, a rotating cylinder driven by the web-to-roller traction, lead most to go unmonitored until degrading performance results in product defects. Idler roller performance is a balance of traction versus opposing forces of drag and inertia. Idler rollers appropriately designed for their specific application will prevent scratching, minimize web tension losses, and ensure good tracking. Past authors have presented simple measurements and models to evaluate bearing drag of an idler roller assembly, but have not presented the complete analysis needed to determine the risk associated with poor idler roller performance.

This paper presents a complete guide based on previously published models and measurement methods to evaluate idler roller performance. Step-by-step instructions show how to use the Spin Down measurements plus bearing drag, roller inertia, and traction models to determine any roller's risk of slipping. A new term is introduced, the Traction Safety Factor, to assess and compare the risk of idler rollers slipping and to identify irregular performance. Beyond the recommended measurements and models, this paper will also review lessons learned in applying this protocol to a coating web line with over 300 idler rollers.

NOMENCLATURE

C	Bearing load rating (N)
F_{BD}	Effective force at the roller's surface to overcome bearing drag (N)
F_{DR}	Available tractional force to drive the roller (N)
g	Gravitational acceleration (m/s^2)
I	Roller rotational moment of inertia (kg-m^2)
K	Bearing life constant (-)
L_{10}	Predicted bearing halflife (min)
M_B	Torque load from bearing drag (N-m)

M_A	Torque load from inertial acceleration (N-m)
N	Roller initial angular speed (rev/min)
P	Equivalent bearing radial load (N)
r_B	Bearing nominal radius (m)
r_I	Roller shell inner radius (m)
r_O	Roller shell outer radius (m)
t	Time (s)
T	Web tension (N)
TSF_A	Traction Safety Factor during acceleration (-)
TSF_{SS}	Traction Safety Factor under steady state condition (-)
V	Roller surface velocity (m/s)
w	Roller width (m)
α_{SD}	Roller angular Spin Down test deceleration (rad/s^2)
α_A	Roller angular acceleration of process speed control (rad/s^2)
θ	Angle of web-roller contact (rad)
μ	Coefficient of friction or traction (-)
ρ	Density (kg/m^3)
τ	Torque (N-m)
ω	Roller angular velocity (rad/s)

INTRODUCTION

Idler rollers are present in abundance on most web processing lines. Their simple design, a rotating cylinder driven by the web-to-roller traction, lead most to go unmonitored until degrading performance results in product defects. Idler roller performance is a balance of traction versus opposing forces of drag and inertia.. Idler rollers appropriately designed for their specific application will prevent scratching, minimize web tension losses, and ensure good tracking.

In his 1996 book [2], Roisum describes a series of simple calculations for estimating bearing drag from coasting idler roller deceleration to calculate tension differential per roller. He recommends keeping total drag for a section, from bearing drag and "inertial tension," to less than ten percent of minimum web tension. Tension differential is also used to determine a "minimum wrap angle to avoid slippage." Roisum's work is an excellent combination of idler measurements and models. In this study, similar simplified models are presented with added insight from the practical application to a production coater.

In their 1997 paper, Dobbs and Kedl described a simple measurement, the *Spin Down* test, similar to Roisum's "drag measurement technique," that provides data documenting the balance of inertia and drag for a specific roller [1]. Though their papers presented data from laboratory measurements, the simplicity and non-destructive nature of the *Spin Down* test is equally applicable to a production environment.

The Spin Down test by itself is an excellent tool to compare identical roller assemblies in an "apples to apples" comparison. Combined with simple inertia and drag models, the Spin Down test data can be used to calculate the drag torque of a roller assembly, allowing comparative analysis of rollers of differing designs.

After measuring and modeling a roller's drag torque the next logical question is "What roller drag torque is acceptable?" The answer is dependent on a specific roller's application. If the roller operates in a web line position with a high combination of wrap angle, tension, and traction coefficient, then there is broad leeway in how high roller drag torque can be without a problem. However, if a roller is applied where there is a low combination of wrap, tension, and traction, there is less room for poor roller performance. Lastly, for accelerating and decelerating processes, the roller inertia and acceleration (or deceleration) rate will add (or subtract) to the roller drag torque, opposing the web-roller driving torque

Rollers will slip relative to the web when the sum of the drag and inertial torques is greater than available driving torque. There are web processes where roller slip is not a problem; however, slipping rollers lead to surface quality defects in scratch-sensitive products and limit the process capability of low-tension processes. Slipping rollers can also create tension and web guiding system instabilities.

TRACTION SAFETY FACTOR

The new term defined in this paper, the Traction Safety Factor (TSF), compares a roller's drag and inertial torque with the demands of its specific application. The TSF is a simple ratio of the driving torque divided by the sum of the opposing drag and inertial torque. Since it is more common to have an intuitive sense for forces rather than torques, the TSF may also be defined as the ratio of the available surface tractional force divided by the surface force required to overcome roller drag and inertia.

The Traction Safety Factor is a clear presentation easily understood by all. How close is a roller to slipping? A TSF less than one predicts a roller will slip. If the TSF is near, but greater, than one, the slightest degradation in roller performance will lead to web-roller slip. A high TSF translates to a low risk of roller slippage.

ROLLER ANALYSIS STEPS

Table 1 shows the steps to finding the Traction Safety Factor for every roller on a given web line This analysis is divided into the following eight steps.

Step	Description
1. Catalog Roller Data	Document all roller positions, noting their ID code, design style, and wrap angle.
2. Complete Spin Down Tests	Measure time to stop from a given rpm.
3. Calculate Roller Inertias	From roller geometry and material, calculate rotational inertia.
4. Calculate Bearing Drag	From roller inertia, spin-down data, and radius, calculate the bearing drag torque and surface force required to overcome bearing drag.
5. Calculate Driving Friction	From wrap angle, tension, and traction coefficient, estimate the available driving traction forces.
6. Calculate Inertial Torque	From target speed and acceleration time, calculate the applied surface force required to overcome inertia and bearing drag.
7. Calculate Traction Safety Factors	From the ratio of driving and drag torques or forces, calculate the TSF for every roller.
8. Review Performance by Bearing and Roller Type	Determine roller improvements based on roller-to-roller comparisons and Traction Safety Factors.

Table 1 – Traction Safety Factor Analysis Steps

1. Catalog Roller Data

The roller performance analysis begins by cataloging all idler rollers on a webline. The data shown in this study was taken on a coater dryer line consisting of an unwind station, several pull rollers, a single coating station, a drying oven, and a rewind station. The total web path length is over 300m with over 300 idler rollers.

The roller wrap angles were estimated from webline elevation drawings. All rollers were confirmed during the roller performance measurements. A more precise wrap calculation can be determined from roller x, y, radius geometry, plus roller rotation and sequence information.

Next, the differing styles of rollers were identified. For most weblines, several common idler roller designs are used throughout the machine. A roller style is defined as a set of rollers having a common bearing design, roller face width, roller radius and shell thickness, material, and web-roller friction characteristics. Beyond the most frequently used roller styles, most weblines will include some one-of-a-kind or infrequent idler roller styles. As we begin to analyze idler roller performance, we will start by comparing rollers with a common style.

2. Complete Spin-Down Tests

The time consuming and costly step of roller performance analysis is completing the Spin Down test on every idler roller. This can be done in a piecemeal manner, testing a few rollers at a time during scheduled downtime. For this study, we chose to complete the work during the night shift, a common downtime for many coating operation.

Spin Down testing is easiest if the web is entirely removed from the webline; however, on a complex coater-dryer line, there may be concerns of threadup errors and startup problems. If the line is unthreaded, make sure an experienced operator or engineer is available to ensure proper rethreading when the tests are complete.

Measurements and Tools. The Spin Down test can be completed with a tachometer, stopwatch, and a short rope. Either a contact or optical tachometer will work, but an optical tachometer can provide continuous data since it does not exert an additional braking drag on the roller. If an optical tachometer is used, a reflective tape strip must be mounted on the roller to detect the revolutions. The stopwatch is used to measure the time to coast to a stop from an initial target angular speed. In place of a rope to accelerate the roller, a cordless drill with a rubber drive puck is an advantageous alternative, especially in tight locations where quickly pulling a rope can lead to scraped knuckles. For each roller record the initial revolutions per minute (or surface speed) and the time for the bearing drag to stop the roller. Figure 1 shows the typical cycle of a Spin Down test.

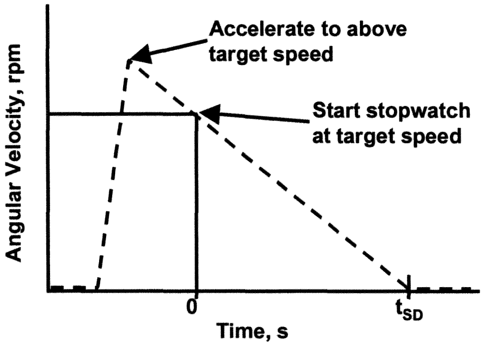

Figure 1 – Spin Down Test Tools

<u>Spin Down Test Protocol.</u> The following steps were repeated for every idler roller to collect Spin Down times.

1. Place reflective tape target on roller face or end.
2. Attach lead end of the rope to roller face.
3. Turn roller 2-3 revolutions to accumulate tape strip or string.
4. Pull rope to accelerate roller to above target rpm.
5. Begin measuring rpm with optical tachometer.
6. When roller slows to target rpm, start the stopwatch.
7. From the target rpm, let the bearing drag slow the roller until it stops.
8. When the roller stops, stop the stopwatch and note the time.

If using a cordless drill to accelerate the roller, steps 2-4 are replaced by "Drive the roller to above target rpms with the cordless drill driven puck."

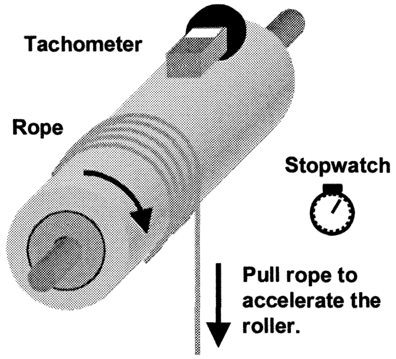

Figure 2 – Spin Down Test

<u>Time Required.</u> Three people working 16 hours completed Spin Down tests on over 300 idler rollers. The work was split with one person spinning the rollers, one person watching the tachometer, and one person timing and recording the data. One or two people could accomplish these measurements by combining tasks if the length of downtime was not cost prohibitive. For longer spindown times, two rollers can be tested simultaneously.

Each roller spun for an average of 60 seconds or a total spin time for 300 rollers of over five hours. The 16 hours of Spin Down measurement downtime worked out to about three minutes per roller or about 20 rollers per hour.

<u>3. Calculate Roller Inertias</u>

The roller shell outer diameter, inner diameter, and width dimensions were estimated from external measurements. Inertia from the bearings or shell end plates were ignored. Inertias were calculated using the following equations.

$$I = \frac{\pi \rho w \left(r_O^4 - r_I^4\right)}{2} \qquad 1$$

Author's Note: Calculating inertia in English units, where density is defined in lbs/in^3, requires consideration for pounds-force vs. pounds-mass; therefore, gravitational acceleration, g in the equation, is added.

$$I = \frac{\pi \rho w \left(r_O^4 - r_I^4\right)}{2g} \qquad 1$$

4. Calculate Bearing Drag

The spin-down test is a simple measurement of the braking time for the bearing drag to counter roller inertia. For simplicity, a simple linear model was used, assuming bearing drag to be independent of load or rpm.

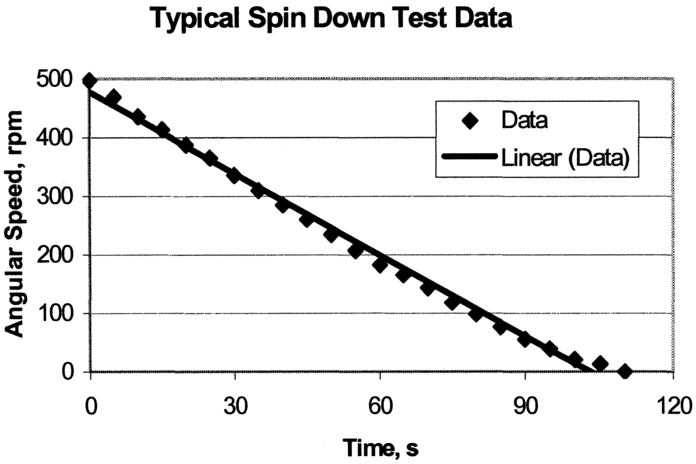

Figure 3 – Typical Spin Down Data

Deceleration rate, α_D, is calculated from starting surface rotational speed and time to stop.

$$\alpha_{SD} = \frac{2\pi n}{60t} \qquad 2$$

Bearing braking torque, M_B, is calculated from roller inertia and deceleration rate.

$$M_B = I\alpha_{SD} \qquad 3$$

Surface force required to overcome the bearing drag, F_{BD}, is calculated by dividing the bearing's braking torque by the roller's radius.

$$F_{BD} = \frac{M_B}{r_O} = \frac{I\alpha_{SD}}{r_O} \qquad 4$$

Previous authors have shown that spindown performance and bearing drag are not strongly dependent on applied load[1]. Though previous authors have shown bearing drag as a non-linear function, for simplicity and based on our typical Spin Down deceleration curves, this study uses a simple linear model.

5. Calculate Driving Friction

Driving tractional force, F_{DR}, is estimated from the wrap angle, tension, and friction coefficient. To calculate a worst-case scenario, the low-end of the typical tension range was used.

$$F_{DR} = \mu T \theta \qquad 5$$

This practical approach to web-roller traction is a simplified model. No application of the band-brake equation is used to define slip conditions as an exponential function of wrap angle. Though tension will vary within a tension zone (due to the drag and inertial loads we are calculating), for simplicity, the tension is considered constant within a zone. Lastly, though there are many documented formulae to calculate web-roller traction coefficient as a function of line speed, tension, radius, air viscosity, web roughness, and roller roughness or profile, this paper uses a simplified constant value for the web-roller traction coefficient.

6. Calculate Inertia Torque

Similar to calculating inertia torque in the deceleration spin-down test, inertia torque during acceleration, M_A, is calculated using target speed and acceleration time. Again, a worst-case scenario was used based on the highest line speed and most aggressive acceleration time.

$$\alpha_A = \frac{v}{rt} \qquad 6$$

$$M_A = I\alpha_A \qquad 7$$

7. Calculate Traction Safety Factor

Traction Safety Factor (Steady-State), TSF_{SS}, is defined as the ratio of the available surface force divided by the surface force required to overcome bearing drag. Traction Safety Factor (Acceleration) , TSF_A, is defined as the ratio of the available surface force divided by the surface force required to overcome bearing and inertial drags.

$$TSF_{SS} = \frac{F_{DR}}{F_{BD}} \qquad 8$$

$$F_A = \frac{I(\alpha_{SD} + \alpha_A)}{r_O} \qquad 9$$

$$TSF_A = \frac{F_{DR}}{F_A} \tag{10}$$

8. Review Performance by Roller Type

Table 2 shows the breakdown of TSF_A values for all idler rollers of this study's webline. No rollers were predicted to slip under the analyzed (worst-case scenario) conditions. Only two rollers were predicted to have a TSF_A less than two, providing a warning for rollers near slipping conditions. The vast majority had a TSF_A much greater than one, indicating a low concern for slipping.

Traction Safety Factor (Accel.) Range	No. of Rollers
< 1	0
1-2	2
2-5	57
5-10	6
> 10	248

Table 2 – Summary of Traction Safety Factor (Acceleration)

It should not be surprising to find no rollers with a TSF less than one. For a scratch sensitive coating operation, quality control or observant operators will notice product scratches and seek to eliminate slipping rollers. However, the advantage of the Traction Safety Factor analysis is the ability to identify rollers that have a poor design for their application or degrading performance approaching a slipping and scratching condition.

Identifying poor or degrading performance is key to scratch prevention. Within a single roller style, simply comparing spindown times shows how much performance variation can occur in what are intended to be identical rollers. Figure 4 shows the Spin Down test times distribution for 72 rollers of identical design (4" diameter, 12mm bearing bore diameter). Spin Down times ranged from 2 to 127 seconds with an average of 66 and mode of 59 seconds.

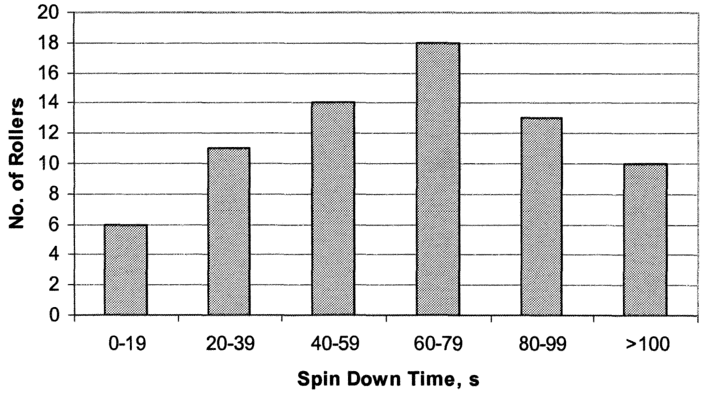

Figure 4 – Spin Down Time Distribution, 4" Diameter Idler

Though there were over 15 unique idler roller designs, most used one of three bearing sizes. The Spin Down analysis allows comparison of bearing performance independent of other roller style variations. A summary of the performance for the three most common bearing designs is shown in Table 3. As expected, smaller diameter bearings have less bearing drag torque. However, the three bearings had a wide variation in calculated drag, each showing approximately a 7:1 performance range.

	Bearing Inner Diameter	Bearing Drag (mode of population)	Bearing Drag Range	Bearing Drag High/Low Ratio
Bearing A	5 mm [0.197 in.]	0.56 N-mm [0.005 lbs-in]	0.23-1.69 N-mm [0.002-0.015 lbs-in]	7.5
Bearing B	12 mm [0.472 in.]	3.39 N-mm [0.030 lbs-in]	2.15-14.8 N-mm [0.019-0.131 lbs-in]	6.9
Bearing C	22 mm [0.875 in.]	7.91 N-mm [0.070 lbs-in]	4.52-32.6 N-mm [0.040-0.289 lbs-in]	7.2

Table 3 – Calculated Performance by Bearings Size

The spin-down test is a measure of present performance, the state of a roller assembly today, and not necessarily a good predictor of future failure. It may seem logical that spin-down performance would degrade over time before ultimate failure (and scratching). However, it is also possible that bearing failure is a catastrophic event, unpredictable by pre-failure measurement.

Bearing Life and Performance

Marks' Mechanical Engineering Handbook lists the following equations to estimate bearing life (L_{10} is the life for a 90% survival rate).

$$L_{10} = \frac{16700}{n}\left(\frac{C}{P}\right)^{K} \qquad 11$$

Table 4 shows the calculated bearing life, L_{10}, for the three bearing sizes. For each bearing analysis, the following variables are held constant: K =3 (K value for ball bearings), N = 430 r/min (calculated from V = 137 mpm [450 fpm]), roller diameter of 102 mm [4 in.], roller shell load was 2.3 N [5 lbs]). Each roller is predicted to have a long life under standard conditions, ranging from 37 to 539 years! However, the smallest bearing, if used in a high wrap location (which it isn't) has a predicted life of only 1.1 years. In a similar application, Marks' recommends bearings for conveyors be designed for 30,000 hrs (or 3.4 years).

Poor Performance Causes

Many factors, beyond the standard bearing load-life equations, may keep a bearing and roller assembly from peak performance, including assembly and environment.

Variability. As an example of performance variations within a set of "identical" rollers, Table 6 shows all the Spin Down times, force calculations, and Traction Safety Factors for 72 rollers of the previously cited 4" diameter idler style. Some of the details on this roller style are listed in Table 5.

Parameter	Variable	Units	Bearing A Low Wrap	Bearing A High Wrap	Bearing B	Bearing C
Bearing Bore	d	mm [in.]	5 [0.197]	5 [0.197]	12 [0.472]	22.2 [0.875]
Tension	T	N [lbs]	115 [26]	115 [26]	115 [26]	115 [26]
Wrap	θ	Deg	5	180	90	180
Static Load Rating	C	N [lbs]	1600 [360]	1600 [360]	3780 [850]	9140 [2055]
Equivalent Radial Load	P	N [lbs]	32 [7.3]	253 [57]	187 [42]	258 [58]
Bearing Life	L_{10}	yrs	539	1.1	37	197

Table 4 – Bearing Life Analysis

Roller Assembly. One of the main sources of performance variability within a roller style is assembly. Ball bearings used in most idler rollers are designed for radial loads and react poorly to lateral (a.k.a. thrust) or torsional loads. Take care in idler roller assembly to not induce high lateral loads with a bearing's locking collars.

Contamination. Contamination can come from many sources: airborne debris, operators, process factors (like slitting, abrasion), and equipment shedding. Bearings are often shielded to reduce contamination concerns, but contacting shields increase drag (not a concern for a high torque application like a motor shaft). To reduce shield drag, labyrinth seal bearings are common for idler rollers.

Thermal Effects. This study did not include testing of rollers at elevated temperatures. This can be an important consideration, especially when roller shell thermal expansion creates axial load against locked bearing collars. When considering thermal expansion, include the first few rollers downstream of an oven since a hot web will conductively heat up the roller shell.

Oxidation. In our study, there was evidence of oxidation degrading bearing performance. Three of the worst rollers were immediately above a corona treater. This points to ozone emission as a source of bearing degradation. Though ozone is heavier than air, oxidation may be seen anywhere along the web path immediately downstream of the corona process since the moving web will entrain ozone gasses.

High Wrap, Cantilevered Rollers. During this study, some of the worst Spin Down times within a roller style were on high wrap angle, cantilevered rollers. The reason for this was unclear. The higher wrap angles create more bearing load from tension. However, several 180-degree wrapped idler rollers supported from both ends did not have sub-par performance. The torsional load from the cantilevered shaft's deflections may increase the bearing load or wear rate.

RECOMMENDATIONS

Monitoring Performance with Tension Differential.

Immediately upon completing Spin Down testing and analysis, you will have new insight into your web line's idler performance variability and know which rollers have the smallest safety factor to avoid slip. However, weeks after this analysis more idler rollers continue to degrade with no simple observation to show if imminent slip conditions may be near. For long, multi-roller tension zones, the differential of two transducer rollers can provide real-time feedback to roller performance changes.

This paper shows how to estimate the surface forces required to overcome opposing torques from bearing drag and inertial acceleration. As an example, the driving force to overcome 72 idler rollers steady-state and accelerating torques is summed at the bottom of Table 6 (25.1 N [5.6 lbs]). This is a measurable tension differential within a multi-roller tension zone. By installing dual transducer rollers within a tension zone, at extreme upstream and downstream locations, the differential between these two tension measurements (when properly calibrated) is a real-time indicator of roller drag, roller performance degradation, and acceleration load swings.

Spin Down Specifications for Roller Assembly.

For many low cost products, on-line tension monitoring or repeated Spin Down testing is too costly relative to the benefits. Even these low cost operations should consider applying the concepts of this study to roller maintenance and new roller installations. A limited survey of roller Spin Down times by roller type is enough information to determine an idler performance standard. Applied to all roller maintenance and new rollers, sub-par performing rollers should never be installed on a web line.

CONCLUSIONS

Cost / Benefit Analysis.

Any projects such as idler roller performance analysis must be cost justified. Management and engineers should rightly scrutinize all project options for their cost and benefit. The cost of Spin Down testing and analysis includes machine downtime, maintenance time, and analysis time. The tools are inexpensive and readily available on most web lines. Obviously, the cost goes up with complicated web lines with hundreds of rollers or fully loaded lines where downtime equals lost profits.

The benefit of roller performance analysis is dependent on a product's sensitivity to scratching or other slip-related defects and the cost of waste. The amount of waste generated by a slipping roller will depend on line speed and frequency of surface quality inspection. Estimate the value of your slip-related waste to justify a roller performance study. If the benefit is high enough, it may justify upgrading from end-of-roll sampling to on-line inspection.

Simplified Measurements and Models

In this study, several concessions were made towards simplified models. Models that are more complex would increase the exactitude of simulation, but would also deter their practical application. Conversely, the simple nature of the measurements and models outlined in this paper is intended to encourage the broader use of idler roller performance analysis.

ACKNOWLEDGMENTS

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Parameter	Variable	Value	Units
Tension	T	57.8 [13]	N [lbs]
Traction coefficient	μ	0.1	--
Target speed	V	137 [450]	m/min [ft/min]
Accel. time	t_a	20	s
Ang. accel.	α	2.25	rad/s^2
Shell Width	w_s	406 [16]	mm [in.]
Shell OD	r_O	51 [2]	mm [in.]
Shell ID	r_I	44.4 [1.75]	mm [in.]
Shell Density (Al)	ρ	2715 [0.098]	kg/m^3 [lbs/in^3]
Angular Speed	n_{SD}	52.4 [500]	rad/s [r/min]
Shell Weight		2.095 [4.62]	kgf [lbs]
Shell Inertia	I	0.0005 [0.042]	kg-m-s^2 [lbs-in-s^2]
Torque of Accel.	M_A	0.011 [0.096]	N-m [lbs-in]

Table 5 – Specific Values for Roller Type X

No.	θ deg	t_{SD} s	α_{SD} rad/s^2	F_{DR} N	F_{BD} N	F_A N	TSF_{SS}	TSF_A
1	4	61	0.9	0.4	0.1	0.3	5.0	1.4
2	4	70	0.7	0.4	0.1	0.3	5.7	1.4
3	90	51	1.0	9.1	0.1	0.3	93.7	29.3
4	180	22	2.4	18.2	0.2	0.4	80.8	41.5
5	4	26	2.0	0.4	0.2	0.4	2.1	1.0
6	4	96	0.5	0.4	0.1	0.3	7.8	1.5
7	4	58	0.9	0.4	0.1	0.3	4.7	1.4
8	4	75	0.7	0.4	0.1	0.3	6.1	1.4
9	4	63	0.8	0.4	0.1	0.3	5.1	1.4
10	4	109	0.5	0.4	0.0	0.3	8.9	1.6
11	4	19	2.8	0.4	0.3	0.5	1.6	0.9
12	4	117	0.4	0.4	0.0	0.3	9.6	1.6
13	20	74	0.7	2.0	0.1	0.3	30.2	7.2
14	90	37	1.4	9.1	0.1	0.3	68.0	26.2
15	4	59	0.9	0.4	0.1	0.3	4.8	1.4
16	4	104	0.5	0.4	0.0	0.3	8.5	1.6
17	4	43	1.2	0.4	0.1	0.3	3.5	1.2
18	4	60	0.9	0.4	0.1	0.3	4.9	1.4
19	4	59	0.9	0.4	0.1	0.3	4.8	1.4
20	180	67	0.8	18.2	0.1	0.3	246.1	63.4
21	4	90	0.6	0.4	0.1	0.3	7.3	1.5
22	4	111	0.5	0.4	0.0	0.3	9.1	1.6
23	4	77	0.7	0.4	0.1	0.3	6.3	1.5
24	180	9	5.8	18.2	0.5	0.8	33.1	23.8
25	90	36	1.5	9.1	0.1	0.3	66.1	26.0
26	4	76	0.7	0.4	0.1	0.3	6.2	1.5
27	4	109	0.5	0.4	0.0	0.3	8.9	1.6
28	4	59	0.9	0.4	0.1	0.3	4.8	1.4
29	4	105	0.5	0.4	0.0	0.3	8.6	1.6
30	90	2	26.2	9.1	2.5	2.7	3.7	3.4
31	4	56	0.9	0.4	0.1	0.3	4.6	1.3
32	4	96	0.5	0.4	0.1	0.3	7.8	1.5
33	90	17	3.1	9.1	0.3	0.5	31.2	18.0
34	4	38	1.4	0.4	0.1	0.3	3.1	1.2
35	4	57	0.9	0.4	0.1	0.3	4.7	1.3
36	20	32	1.6	2.0	0.2	0.4	13.1	5.5

Table 6 (Part 1 of 2) – Traction Safety Factor, All Rollers Type X

No.	θ deg	t_{SD} s	α_{SD} rad/s^2	F_{DR} N	F_{BD} N	F_A N	TSF_{SS}	TSF_A
37	20	94	0.6	2.0	0.1	0.3	38.4	37
38	4	70	0.7	0.4	0.1	0.3	5.7	38
39	4	75	0.7	0.4	0.1	0.3	6.1	39
40	4	64	0.8	0.4	0.1	0.3	5.2	40
41	4	88	0.6	0.4	0.1	0.3	7.2	41
42	45	17	3.1	4.5	0.3	0.5	15.6	42
43	4	69	0.8	0.4	0.1	0.3	5.6	43
44	4	93	0.6	0.4	0.1	0.3	7.6	44
45	120	20	2.6	12.1	0.2	0.5	49.0	45
46	4	68	0.8	0.4	0.1	0.3	5.6	46
47	4	127	0.4	0.4	0.0	0.3	10.4	47
48	80	35	1.5	8.1	0.1	0.4	57.1	48
49	4	98	0.5	0.4	0.1	0.3	8.0	49
50	180	11	4.8	18.2	0.4	0.7	40.4	50
51	4	81	0.6	0.4	0.1	0.3	6.6	51
52	4	97	0.5	0.4	0.1	0.3	7.9	52
53	4	62	0.8	0.4	0.1	0.3	5.1	53
54	180	55	1.0	18.2	0.1	0.3	202.0	54
55	4	52	1.0	0.4	0.1	0.3	4.2	55
56	4	117	0.4	0.4	0.0	0.3	9.6	56
57	4	75	0.7	0.4	0.1	0.3	6.1	57
58	4	88	0.6	0.4	0.1	0.3	7.2	58
59	4	55	1.0	0.4	0.1	0.3	4.5	59
60	4	117	0.4	0.4	0.0	0.3	9.6	60
61	4	106	0.5	0.4	0.0	0.3	8.7	61
62	4	57	0.9	0.4	0.1	0.3	4.7	62
63	180	27	1.9	18.2	0.2	0.4	99.2	63
64	4	88	0.6	0.4	0.1	0.3	7.2	64
65	20	40	1.3	2.0	0.1	0.3	16.3	65
66	4	58	0.9	0.4	0.1	0.3	4.7	66
67	4	79	0.7	0.4	0.1	0.3	6.4	67
68	4	39	1.3	0.4	0.1	0.3	3.2	68
69	4	37	1.4	0.4	0.1	0.3	3.0	69
70	4	72	0.7	0.4	0.1	0.3	5.9	70
71	4	98	0.5	0.4	0.1	0.3	8.0	71
72	4	92	0.6	0.4	0.1	0.3	7.5	72
Σ					**9.8** **[2.2 lbs]**	**25.1** **[5.7 lbs]**		

Table 6 (Part 2 of 2) – Traction Safety Factor, All Rollers Type X