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# THE ADVANTAGES OF INERTIAL ROLL ALIGNMENT TECHNOLOGY IN ESTIMATING WEB HANDLING ISSUES

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## ABSTRACT

Roll alignment plays a crucial part in eliminating web handling issues in manufacturing processes. Web handling issues due to roll misalignment includes tracking, tension control, uneven material gauge, and in some cases, misalignment alters the molecular properties of the material being produced.

While the pace of the manufacturing industry has evolved, with machines today running faster than ever, commonly used roll alignment methods such as such as theodolites and transits has not change much. Such systems inherently contain errors as well as geometrical limitations in measuring rolls in machinery of various configurations. A few of these issues were addressed by the newer laser alignment devices but these systems still need to be set up roll by roll with a line of sight, therefore consuming valuable time.

These issues are addressed with the invention of the inertial roll alignment method. The inertial roll alignment device eliminates geometrical limitations due to its highly engineered and compact design. The device does not require a line of sight because it has three ring laser gyroscopes that measure the x-y-z positions (or roll, pitch and yaw) of a roll in space. The inertial roll alignment method eliminates errors that are present in the other methods. The advantages of inertial roll alignment device are in terms of higher accuracy, precision, speed of data collection, compactness, and no line of sight needed. If rolls in machinery are aligned with the inertial roll alignment device, manufacturing processes would expect less web handling issues.

## INTRODUCTION

Roll alignment plays a crucial part in determining the web path of material through machinery as well as the quality of the end product. Symptoms of misalignment oftentimes manifest as web handling issues, such as uneven thickness, breakages or fissures in material, and tracking off the intended path.

Roll misalignment is the source of shifts in lateral or longitudinal directions of web, resulting in material running off the machine and the creation of uneven tension forces in the web. Uneven tension can cause uneven thickness in material by stretching. This not only affects the appearance but changes the material's molecular property. Industries dealing with paper, film, foil, and packaging materials are sensitive to the effects of misalignment. If stretching is severe enough, it would lead to fissures and breakages of the web. Paper breaks are a common problem found in the paper industry and the main cause of downtime (please see section on financial cost of web breaks and downtime). Another source of uneven thickness is the uneven application of coating on the materials in the steel and printing industry. Such problems affect the quality of the end-product, increase scrap, and cause unplanned downtime. Correcting roll alignment of machinery improves the overall web handling of the machinery.

**Brief Background of Roll Alignment Technology**

Various means of roll alignment methods being used today include precision levels, precision diameter tapes, theodolites, laser trackers, and so on.

A precision level is used to measure the level (vertical offset) of the rolls. The level has graduated lines that denote the precision of the level. As with any other spirit level, the precision level is checked by placing it on a roll, noting the position of the bubble then rotating the level 180°; the bubble should be in the exact position if no error exists.

A precision diameter tape has etched graduated lines that denote circumferential distance. The tape can be used to measure the square (horizontal offset) of rolls that are in close proximity and assist in tramming (aligning) the rolls. This is done by measuring the two rolls on one end (e.g. machine side), obtaining the measurement then measuring the same rolls on the other end. Then, the rolls can be adjusted to eliminate the difference. A pair of tapes can also be used to simultaneously measure both ends.

The theodolite is an optical instrument that has been in existence as early as the 16$^{th}$ century [1]. The theodolite in use today is based on the model created by Jesse Ramsden in 1787 [2]. It is mainly used for topographical surveying but is adapted to other applications including the surveying of roll alignment. The necessary equipment for measuring roll alignment with optical systems include the theodolites or telescopic transit squares, sight level, optical scales, and monuments. First, the centerline of the machine is determined. Next, monuments (brass plugs or stainless steel bushings) are inserted in the ground to form a baseline (which is a line parallel to the machine centerline, outside the machine). Then, a fixed or master theodolite is positioned along the baseline while a second theodolite is moved from roll to roll to measure the alignment of the rolls. At each roll, the second theodolite's scope has to be aligned with the master theodolite's and then perfectly turned 90° to read the optical scales set up on the rolls. A telescopic transit square may be used in the place of a second theodolite to minimize the time and index error[1] that occurs when the theodolite is plunged (turning the scope from one position to another). The master theodolite cannot be moved throughout the entire procedure or it would result in additional errors.

The disadvantage of the optical roll alignment system is that the procedures inherently depend on the observer. Firstly, visual acuity is dependent on the cornea; the shape and the refractive index vary from person to person and deteriorate with age [3]. According to the World Health Organization fact sheet, refraction error disorders affect at least 153 million worldwide. While structural defects in the eye such as keratoconus affects 15 million Americans according to a low estimate by the National Eye Institute [4].

Furthermore, an optical instrument is subjected to parallax error. Parallax is a difference in observation caused by the change in position of the observer[1] [5]. Parallax can occur in reading needles on scales from slightly different positions. One small error in the setup is easily propagated throughout the system; therefore, it takes time and care to set up such a system roll by roll.

Most laser tracker systems have a setup similar to optical instruments where the laser sensor and emitter could be mounted with tripods. In another type of setup, a laser emitter device is strapped on a roll while a sensor device is strapped on another roll to be measured. This system is somewhat easier to set up as it requires less equipment. The accuracy of the readings from a laser system is not affected by the user unlike the optical system; however, this system is susceptible to environmental conditions such as humidity. Laser (which stands for Light Amplification by Stimulated Emission of Radiation) has similar properties like light and thus, will refract in a medium like water. Water droplets in the atmosphere can bend and scatter the laser beam from the emitter [6] and cause errors in the set up and subsequently, the readings.

Laser systems are far more accurate compared to the optical systems as it eliminates the role of the observer. However, this is only true if both systems are compared in a controlled setting (laboratory). In the real world, both are affected by suspended water molecules bending the direction of light, resulting in reduced accuracy.

The main disadvantage of both the optical and laser systems is that they require a clear line of sight for the systems to be effective. Obstacles such as machinery frames, enclosed chambers, walls, and different levels hinder a clear line of sight. Due to this reason, certain machinery configurations are severely limited by these methods.

## Methods of the Inertial Roll Alignment Technology

The approach to the inertial roll alignment method is to eliminate the need for a line of sight, human errors associated with reading measurement data, and effects of the atmospheric conditions. The inertial roll alignment device is able to measure cylindrical, crowned, segmented, suction, embossed, corrugated, Yankee cylinders and ceramic rolls.

The inertial roll alignment device contains three He-Ne ring laser gyroscopes that measure the 3 degrees of freedom of the roll (x-y-z positions or roll, pitch, and yaw) in space. The gyroscopes detect the phase shift in the wavelength of the laser beam as the device is rotated around the axis of the roll. The gyroscopes used in the inertial roll alignment device are also used in aerospace, aircraft, and unmanned system applications [7].

The device is compact and has a relatively simple setup. First, a calibration plate is set up parallel to the machine. This is a one-time setup per machine. The plate is held in place with epoxy glue that takes thirty to forty-five minutes to harden. The purpose of the calibration plate is to measure the Earth's rotation rate and allows the device to find its orientation in respect to Earth's rotation; this process takes 5 minutes to complete. The Earth rotates at a rate of 15.041° per hour or 1.253° every 5 minutes.

Next, the Link roll is measured. The Link roll is an arbitrary roll that is chosen in the machine and must have properties such as cylindrical, metallic, easy to access, and is

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[1] Index error: Half of the difference from one position to another.

[2] Parallax: "Apparent displacement, or difference in the apparent position, of an object, caused by actual change (or difference) of position of the point of observation; spec. the angular amount of such displacement or difference of position, being the angle contained between the two straight lines drawn to the object from the two different points of view, and constituting a measure of the distance of the object."

fixed for the entire duration of the measurement. Other rolls in the machine are then measured in the twenty-minute time frame – each roll would take about 30 seconds to measure - and again the Link roll is measured. The purpose of the Link roll is to compensate for errors that accumulate as the rolls drift in space due to the Earth's rotation and to link all the sets of measurement to the same coordinate system.

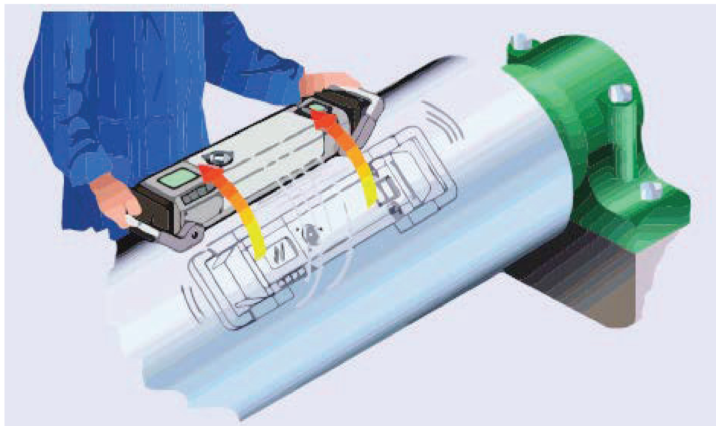

Figure 1 – Measuring an axis of a roll with the inertial roll alignment device in "Sweep" mode

The procedure to measure a roll requires a minimal 20 degrees of access around the roll surface for a regular "Sweep" (Figure 1). The device is placed on the roll and then swept along the surface or the roll can be rotated while the device is held in place. Another mode is the "Crowned Sweep", where the roll is measured with a minimum sweep of 150° in case a regular sweep does not yield good readings due to the bad surface area on the roll such as wavy profile, pits or dents. In such cases, ratchet straps may also be used to strap the device down on the roll and the roll is rotated to obtain readings.

As a roll is being measured, the data collected by the gyroscopes is sent from the device to a laptop computer via Bluetooth™ signal. The vertical and horizontal alignment offsets (respectively known as V and H) on the roll instantly shows up on the graphical display in the software.

The device and software eliminates human errors as the system will stop taking measurements if the device is held skewed on a roll. This is noticeable by the absence of the ticking sound produced when the device is taking data.

The reference roll is an arbitrary roll chosen as a zero point position. The alignment offsets of the other rolls are relative to the reference roll. Any roll can be chosen as the reference roll (V: 0.000", H: 0.000") and is easily changed with a click of a button. The ability to easily change the reference roll makes it easier to analyze the results and determine the least amount of rolls to move. The choice of reference roll depends on the importance of the roll in the process or the difficulty in aligning that roll. For example, in a cast film line a good choice for the reference roll is the Casting Drum while in a tissue machine it is the Yankee Cylinder or the Through-Air-Dryer. These rolls are chosen as the reference roll because they are crucial to the manufacturing process as well difficult to adjust.

The reference roll does not indicate whether a roll is leveled to the Earth or squared to the centerline of the machine because the device only measures the parallelism between rolls. If there is a roll that is already leveled or squared, that roll could be used as a reference or if there are optical readings available, the inertial roll alignment software is able to integrate into the results from the inertial roll alignment device.

**Financial Cost of Web Breaks and Downtime**

Misaligned rolls can cause web breaks in a production line. Web breaks are not just a hassle to operators but have a tangible consequence that affects production bottom line. Table 1 illustrates the financial cost of extra downtime (loss of gross profit) in a newsprint paper machine when paperbreaks increased from 2 to 5 times a day with only 10 minutes downtime each time.

| Paper Type | Speed (m/min) | Width (m) | Weight (g/sqm) | Price (USD/1000 kg) | Turnover (USD/hour) |
|---|---|---|---|---|---|
| Newsprint Paper | 1,300 | 7 | 48 | $585 | $15,331.68 |

| Paper Type | Paper break /day | Downtime/ Paperbreak (minutes) | Turnover (USD/ hour) | Loss/day (USD) | Loss/Year (USD) | Additional cost in production |
|---|---|---|---|---|---|---|
| Newsprint Paper | 2 | 10 | $15,331.68 | $5,110.56 | $1,865,354.40 | $2,798,031.60 |
| Newsprint Paper | 5 | 10 | $15,331.68 | $12,776.40 | $4,663,386.00 | |

Table 1 – Financial Cost of Paper Breaks for Newsprint Paper Line (10 minutes downtime per paper break)

The inertial roll alignment device can be used to align rolls during felt and wire changes in a paper machine which occurs every few weeks. This downtime usually last a few hours and in that short time, the device can measure a section of the paper machine (about 20 to 30 rolls, due to advantage in measurement speed) ensuring good alignment before the machine returns to production.

If rolls in a machine are aligned, web breaks would be reduced, quality of end product would improve, tracking problems would lessen, and the cost of manufacturing would decrease.

**Conclusion**

Web handling issues can be reduced when rolls are aligned. In the previous sections, the technologies that exist today for roll alignment are compared and contrasted. Optical and laser systems are difficult to set up consuming valuable time in a short shutdown. Both systems require a clear line of sight to be effective and are also affected by environmental conditions which can result in reduced accuracy.

The inertial roll alignment device is the next generation of alignment technology. Not only does the inertial roll alignment technology have the advantage of speed in measuring rolls during a short downtime, the device works well in confined spaces such as vacuum metalizing chambers, annealing furnaces in steel mills; machinery on different levels such as blown film lines, steel mills, and wherever a clear line of sight does not exist. The inertial roll alignment technology also eliminates human errors and environmental factors that affect the other alignment technologies. The inertial roll alignment software is also able to integrate optical readings into the readings from the inertial roll alignment device, incorporating a great feature (absolute positions to the Earth and machine centerline) from the optical technology into the inertial technology.

Since the inertial roll alignment device is not constrained by a need for line of sight, a majority of rolls in a machine can be fully measured. This would result in a picture of where misalignment of rolls can clearly be seen and would aid in troubleshooting problem areas with the goal of decreasing web handling problems and cost per tonnage of production.

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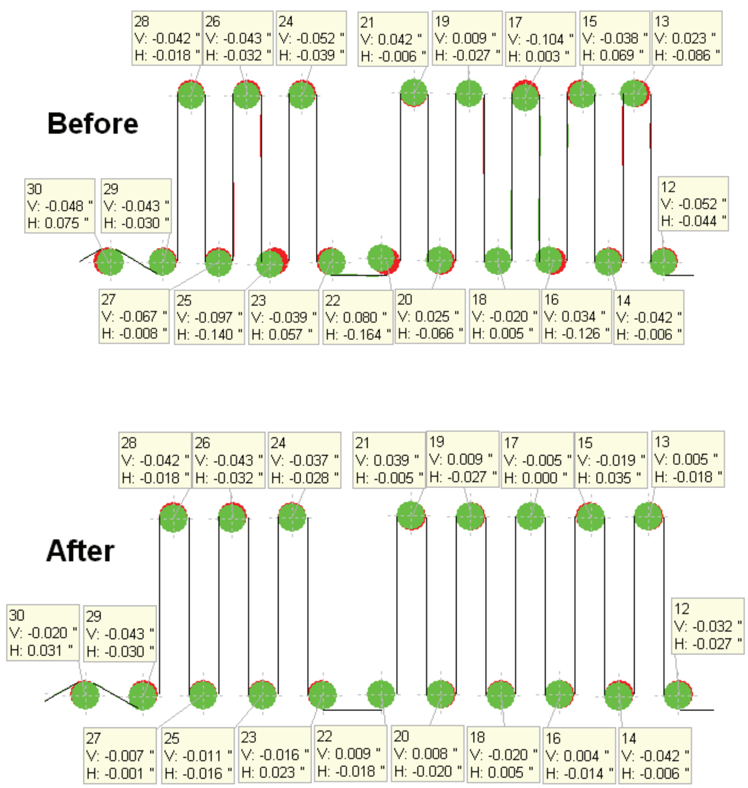
**APPENDICES**

**<u>Appendix A</u>: Example of a Machine with Rolls on Multiple Levels**

**Appendix B1: Measuring a Roll in an Annealing Furnace Chamber, where there is no line of sight**

**Appendix B2: Protocol of Rolls in an Annealing Furnace, initial results and after alignment of the rolls**



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| ***The Advantages of Inertial Roll Alignment Device in Eliminating Web Handling Issues*** | **C. Woo,** PRÜFTECHNIK Service, Inc., USA |

| **Name & Affiliation** | **Question** |
|---|---|
| Gary Strike, Webtech Omega, LLC | In addition to web break data, were you able to detect any difference in edge guiding data or any other types of data feedback that showed improvement? |
| **Name & Affiliation** | **Answer** |
| Chiu Yen Woo, Prüftechnik Service, Inc. | In the case study there was no change in the process like tension control. There were only roller misalignment issues. |
| **Name & Affiliation** | **Question** |
| Jim Dobbs, 3M Company | I have a limited experience with your system. Our situation is different from a big paper mill in that we were attempting, maybe unwisely, to measure selected problem rollers in several machines in one 8 hour workday. A couple of things became pretty apparent. 45 minutes into the test the device had to get reoriented to the earth, re-stabilized, as we moved throughout the factory and that was a little challenging. Multiple tests had to be setup because the machines were 100 meters apart from each other. The 5 minute operating window is also a little challenging, especially when climbing 3 stories up to the next roller. Not needing line of sight is great, but if you are measuring a roll up in your oven three stories up and your reference roll is maybe somewhere down on the ground – you get really tired going up and down three stories with this device. The size of it is probably OK if you are working on a paper mill or large printing machines. Our machines are smaller in scale, so I'm waiting for the compact version of your device that weighs no more than 10 pounds and can measure accurately. You didn't talk about the rotation requirement. You have to be able to rotate the instrument a certain number of degrees around the roller (20 degrees minimally). Some of us would be unable to rotate the instrument 20 degrees without colliding with another roller. I am waiting for the next generation, it is great technology, but it is still in its infancy in terms of potential. I am sure it will enjoy widespread usage and success when some other practical issues are addressed. |
| **Name & Affiliation** | **Answer** |
| Chiu Yen Woo, Prüftechnik Service, Inc. | The 5 minute period is the length of time the device must sit on the reference roller. You then have a 20 minute window to measure all the rolls. I have done more than 3 stories, 6 stories. It was a 2 day service, 12 hours a day. In 6 hours we measured the machines. In terms of distance, it doesn't really matter, you just carry the device. You |

| | |
|---|---|
| | mentioned that the machine needs to be smaller, how much smaller? We don't care about the diameter of the rolls, so 20 degrees is pretty small rotation requirement. |
| **Name & Affiliation** | **Comment** |
| Jim Dobbs, 3M Company | A 5-roll coater puts several rollers into a confined space. |
| **Name & Affiliation** | **Comment** |
| Doug Offerhaus, Catalyst Paper | I've been involved with engineering metrology, in particular optical tooling for the last 28 years and I teach the subject as well, so I can answer your question regarding the accuracy of optical tooling instruments. Typically, we employ first order instruments which are capable of reading within 1 arc second of angle. To put that into perspective, imagine a long slender triangle with a 1 second included angle. If the legs of that triangle are 17 feet long, the base of the triangle would be 0.001 inches. This is the level of tolerance the first order instruments are capable of. When we are working on paper machines on nip rolls and winders, the typical tolerances that are required by OEMs are 0.005 inches or less, total, not +/-. You quote an accuracy capability for your Paralign instrument of 0.005 inches for a roller that is 100 inches wide. Typical process winders can be 200-300 inches wide. The accuracy of the Paralign would be 10-15 thousandths of an inch. That's not accurate enough for most high speed winders. |
| **Name & Affiliation** | **Answer** |
| Chiu Yen Woo, Prüftechnik Service, Inc. | The precision quoted is when we make one measurement at the center of the roll. For a roll 100 inches wide, we measure at 2 or 3 locations across the width and that improves the accuracy. The more measurements you make improves the average and the accuracy. It depends on case by case. We have done this before and sometimes we get down to 0.002 in the paper machine which often is over 300 inches wide. |
| **Name & Affiliation** | **Comment** |
| Doug Offerhaus, Catalyst Paper | When the Paralign technology was introduced, I enthusiastically pursued it because I recognized the potential benefits that were identified. We ran tests comparing the Paralign with traditional optical techniques at our mill. The first tests were conducted on a calendar stack. We shot the rolls optically and measured with the Paralign. The results did not agree. I invited the Paralign representative to return to our mill at a future shutdown. We ran tests on rolls that were sitting on blocks. We had another roll that could be used for a reference roller. We had two measurement groups, the optical and the Paralign team, both groups were asked to leave the room. We used dial indicators and shims to adjust the rollers in vertical and horizontal planes; we knew how much the target rollers were moved. We then invited both teams to return and |

measure alignment of the target roller in comparison to the reference roller. The optical team was able to measure the change in alignment within 1 or 2 thousandths of an inch. Unfortunately, the Paralign was not able to do so. We repeated that test two or three times. We concluded that although the Paralign was a great instrument, it is not at this point adequate for the precision alignment. It is good for aligning rollers that require less precision. I am keen to see the Paralign technology developed further because I think it has further potential.