

Parent reel and spool handling with automatic guided vehicles—A case study

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ABSTRACT: *As the size, expanse, and speed of papermaking operations increase, so does the need to critically evaluate the methods and equipment used to transport parent reels and spools. Traditional methods of reel and spool handling that utilize bridge cranes, rail carts, and tugger/wagon arrangements have inherent costs and limitations as the size and speed of operations grow. Automated guided vehicles provide a feasible alternative.*

KEYWORDS: *Automatic systems, guided vehicles, jumbo rolls, materials handling, reels, spools, vehicles, wound rolls.*

This paper discusses the experiences of one mill with the evolution of a specific heavy load parent reel and spool handling automatic guided vehicle (AGV) system from concept and justification through startup and initial performance. Highlights of this discussion include: justification of AGVs versus rail carts, AGV system specifications, floor and battery considerations, acceptance testing and startup, and initial performance recap.

Heavy load AGVs and their application to reel and spool handling in the paper industry is a relatively new approach to a century-old material handling issue. The experience gained in this area at Consolidated Papers, Inc. will be valuable to other mills evaluating similar applications

of automated material handling technology.

Background

On Oct. 17, 1989, Consolidated Papers, Inc. approved a US\$ 495-million expansion of its coated free-sheet papermaking operations in Wisconsin Rapids, WI. The new machine, called No. 16, was designed to produce coated printing papers at a rate of 192,300 tons/year (metric). From the paper machine, reels proceed through a re-reeler, one of two off-machine blade coaters capable of running alone or in tandem, one of two supercalenders (except for matte grades), and the finishing winder (**Fig. 1**). A centrally located reel/spool storage area provides surge

capacity between operations. A new salvage rewinder, additional converting capacity, and automation of the roll and finished goods handling and storage systems were also included with the No. 16 project.

Consolidated's Industrial Engineering department was assigned the task of evaluating the reel and spool handling requirements for the No. 16 facility. The goal was to provide a cost-effective material handling solution while safely maintaining the required production throughput.

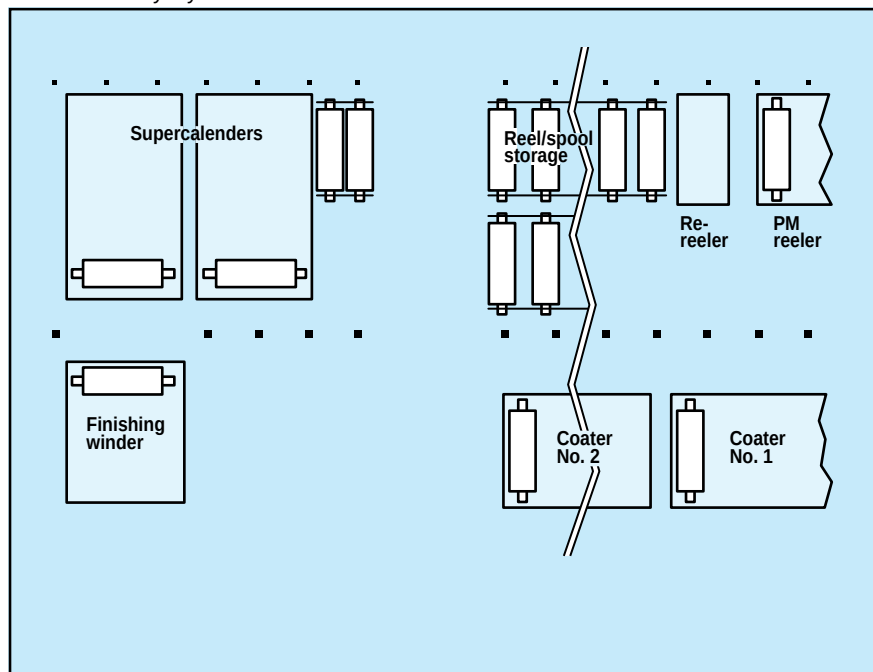
Reel and spool flow

The movement of reels was complicated by the fact that the building was split into two "halls" separated by a column line. The paper machine hall contained the paper machine, re-reeler, reel storage area, and supercalenders. The coater hall contained the two coaters and the finishing winder. Reels going to or from the coaters, or from the supercalenders to the winder, needed to pass through the column line, which could not be accomplished with a standard bridge crane. Furthermore, the unwind stands of the two coaters were under the sheet run, which made them inaccessible from above.

Access to the coater unwinds was provided by rail carts supplied by the coater manufacturer. These carts extended through the column line into the paper machine hall to facilitate bridge crane loading, and had

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1. No. 16 facility layout



the capability to automatically unload a reel into the coater unwind.

Reel movement from the supercalenders to the finishing winder was accomplished with transfer rails extending from the winder unwind through the column line. These transfer rails linked up with a rail cart capable of receiving reels from either of the two supercalenders and ejecting them onto the transfer rails.

Spool flow philosophy was to reduce the reliance between different departments by having spools go from the unwind to windup on the same piece of equipment rather than being transferred back to the previous operation. This ensured that an extended downtime on one piece of equipment would not affect the spool supply to an upstream operation. While this approach works well for the internal operations (re-reeler, coaters, supercalenders), it forces the spools from the finishing winder to go back to the paper machine, the most distant operations in the facility separated by approximately 200 m.

Given the preceding material handling solutions, the remaining reel

and spool handling issues were (a) reel transfers from the coaters into the paper machine hall and (b) spool transfers from the finishing winder to the paper machine.

Initial proposal for AGV usage

The primary papermaking equipment manufacturer for the No. 16 project proposed using three rail carts on dedicated tracks to address these two remaining handling issues. Each coater windup would be served by a rail cart on a straight track section for transferring coated reels into the paper machine hall. The third rail cart would be used for moving spools from the finishing winder back to the paper machine. Since this option involved the undesirable installation of over 275 m of rail on the operating floor, alternative solutions were sought.

Initially, the transporting of coated reels and spools was considered as separate issues. The idea of using one AGV to move coated reels from either coater back to the paper machine hall was developed as a way to reduce the capital cost associated with the proposed two rail carts and

associated trackage. Alternative methods for returning spools to the paper machine ranged from an overhead monorail system to lowering the spools into an AGV or rail cart located in the basement in order to keep the long run off the operating floor. Ultimately, the idea of combining the coated reel and spool return requirements into one system is what sold the AGV concept. **Figure 2** shows an AGV being loaded with a reel of paper.

Comparison of AGVs vs. rail carts

It was felt that a two-vehicle AGV system could perform the reel and spool handling duties of the three rail cart system proposed by the papermaking equipment manufacturer. Investigations into the use of heavy load AGVs yielded the following comparative advantages and risks of using AGVs vs. rail carts.

Advantages of AGVs

Capital cost. Whereas an AGV will typically cost more than a rail cart due to the additional controls and safety features, this vehicle cost may be offset by the material and installation costs of a steel rail versus a wire guide path. As the length of the run increases, the less expensive wire guide path installation (typically 20–30% of steel rail) offsets the greater expense of the AGV. For example, if the vehicle cost for a rail cart was US\$ 50,000 less than an AGV, the rail material and installation costs were US\$ 500/m, and wire guide path material and installation costs were US\$ 125/m, an AGV system would become less costly than a rail cart system as the length of the required path exceeded 135 m (US\$ 50,000/US\$ 375/m). Furthermore, intersections and alternate paths can be managed by a wire guide path without the expense of rail diamonds or mechanical switches. Changes or extensions of the guide path are also relatively inexpensive.

Reel Transport

Labor cost. Compared to manual material handling options such as tuggers and wagons or bridge cranes, AGVs offer reduced labor requirements. Since AGVs travel unattended, are remotely called and dispatched, and may even be automatically loaded and unloaded, the labor element can be totally removed from a material handling function. This equates to reduced labor costs or additional time for the existing labor force to concentrate on productivity and quality issues.

Safety/Aesthetics. Since AGVs run on flat, hardened surfaces, the flange gaps associated with rail installations are avoided. These gaps are a tripping hazard, housekeeping problem, and an eyesore.

Maneuverability. AGVs can turn on a 6–9 m radius through building columns or may be manually controlled off the guide path.

Redundancy. Since the AGVs in a two-vehicle system would have access to all areas of the guide path, one vehicle could serve the facility for a period of time if the second vehicle were temporarily out of service. With railed vehicles, downtime puts an entire section of path out of service while that vehicle is being repaired.

Remote Communications. The wire guide path used with AGVs also serves as the communication link between the vehicles and the various pickup and delivery locations within the facility. Regardless of the current location of the AGVs, an operator's request for pickup or delivery will be transmitted to the first available vehicle for execution.

Risks associated with AGV usage

Being a first-time user of heavy load AGV technology, we had a number of questions associated with the use of AGVs when compared to rail carts.

Complexity/Familiarity. Rail carts are common throughout Consolidated's operations and require relatively simple and proven technology. AGVs incorporate a

2. Reel and spool handling AGV in the No. 16 facility



higher level of control and guidance technology which would be new to Consolidated.

Maintenance. With the exception of cord reels on ac-powered vehicles, rail carts do not require frequent maintenance attention. It was felt that the maintenance requirements for AGVs would be greater than for rail carts; however, the magnitude of this difference was unknown.

Floor Wear. Without the benefit of a steel rail to ride on, the floor wear created by the exact tracking of a heavy load AGV was an issue. There are a number of options available to enhance the wear surface (i.e., epoxy coatings and concrete additives); however, the history of heavy load AGVs was not long enough to make predictions of floor condition beyond five years.

Power/Batteries. ac cable reels are a straightforward method for powering rail carts on short tracks (less than 65 m). AGVs would involve a dc battery-operated system requiring either periodic battery removal for charging or the design of an opportunity charging arrangement where the batteries get charged automatically while the AGV is idle. Once again, the relative newness of

heavy load AGVs precluded the determination of a “best” power supply system.

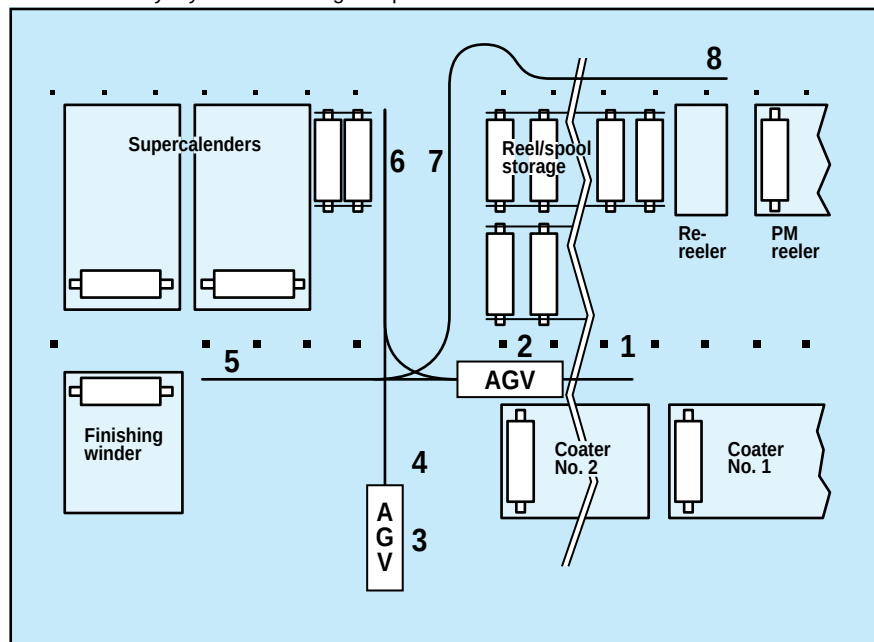
Investigations into AGV technology

Before committing to the AGV approach for coated reel and spool handling on the No. 16 project, further investigation into existing applications of heavy load AGVs was necessary. Visits to installations in other paper mills, heavy equipment manufacturing operations, and primary metal producers provided a good mix of information and opinions regarding Consolidated's proposed application of AGVs. In particular, the issues of battery/charging options and floor construction received special attention.

Battery/charging options

There are two approaches for charging AGV batteries. The batteries may be deeply discharged, removed from vehicle, and replaced with a different, fully charged set. This involves periodic (once per shift or daily) interruption of the vehicle's activities and typically three sets of batteries

3. No. 16 facility layout with AGV guide path



per vehicle (one operating, one charging, and one cooling). Standard flooded cell lead-acid batteries are the simplest and most cost-effective approach for this option.

If frequent battery replacement is undesirable or impractical, opportunity charging may be employed. With opportunity charging, specific locations along the guide path are equipped with charging plates which automatically engage and charge the vehicle's batteries when it is at that location. This amounts to giving the batteries frequent, relatively short charges versus the long, full cycle charge given to batteries removed from the vehicle.

The installations visited all employed opportunity charging with their AGV systems, but the battery type differed from plant to plant. Fiber-nickel-cadmium (FNC), lead-acid paste, and lead-acid flooded cell batteries were all being used. FNC batteries are specifically designed for short duration, high amp charging, but had a limited history in heavy-load AGV applications and are significantly more expensive than lead-acid batteries. A concern with flooded cell lead-acid batteries used in an opportunity charging scheme

is the stratification of the electrolyte if the battery is not given a longer "equalizing charge" periodically (every 1–2 weeks). This stratification, or layering, of the electrolyte can cause uneven wear of the battery plates, shortening the life of the battery.

It was decided to utilize opportunity charging of large capacity, flooded cell lead-acid batteries for the No. 16 project AGVs, with special consideration given to a battery rotation and maintenance scheme to minimize the effect of stratification. The battery storage cavity on each AGV was equipped with a roller bed conveyor to facilitate battery removal and replacement.

Floor construction

Three aspects of floor construction will affect the performance of a heavy load AGV system: structure, wear surface, and levelness.

Structure. The floor structure must be designed to support the combined weight of the vehicle and load with consideration given to the impact when loading. The vehicle design will determine the required point loading based on the number

and type of support points (wheel or casters) utilized by the vehicle. To facilitate guide path installation and operation, the floor should be free of rerod, anchors, etc., within 5 cm of the surface along the guide path.

Wear Surface. The heavy weights combined with the exact, repetitive tracking of an AGV presents an abrasive floor wear problem. Various approaches to dealing with this problem were noted while visiting facilities using heavy load AGVs. The methods ranged from epoxy or urethane coatings to additives such as iron filings or hard aggregate materials included in the concrete. Static charge buildup is a concern with some epoxy coatings. The tractive force requirements to start and stop the AGV also need to be kept in mind when designing the wear surface so a "slippery" condition is not created.

Levelness. Since the length of an AGV handling a reel or spool could be 10 m or more, the levelness of the floor is important to ensure that the vehicle does not "bottom out" or have wheels/casters not contacting the floor over sections of the path. Noncontacting wheels could create a traction/slippage problem and would increase the point loads carried by the wheels remaining in contact. As a general rule, floors should be flat within ± 1 cm per 5 m.

When the operating floor was poured in the No. 16 facility, a "trough" was left in the area of the AGV guide path to facilitate the installation of a thicker (36 cm) slab compared to a 15- to 20-cm slab under the standard floor. An iron filing concrete additive was troweled into the surface of the guide path slab to enhance wear resistance. Concrete with a specification of 27,500 kPa (4000 psi) was used throughout the operating floor area, including the guide path. Once the system was operational, the guide path received extra sweeper coverage to keep dust and debris from accelerating the wear process.

Reel Transport

AGV system specification

Up to this point, there had been an active exchange of information and ideas between Consolidated and suppliers/users of heavy load AGV systems. Based on this information and the budget proposals received, the decision was made to utilize a two-vehicle AGV system for coated reel and spool transport in the No. 16 facility. A detailed specification was prepared to define the system and installation requirements and responsibilities. The primary sections of the specification were:

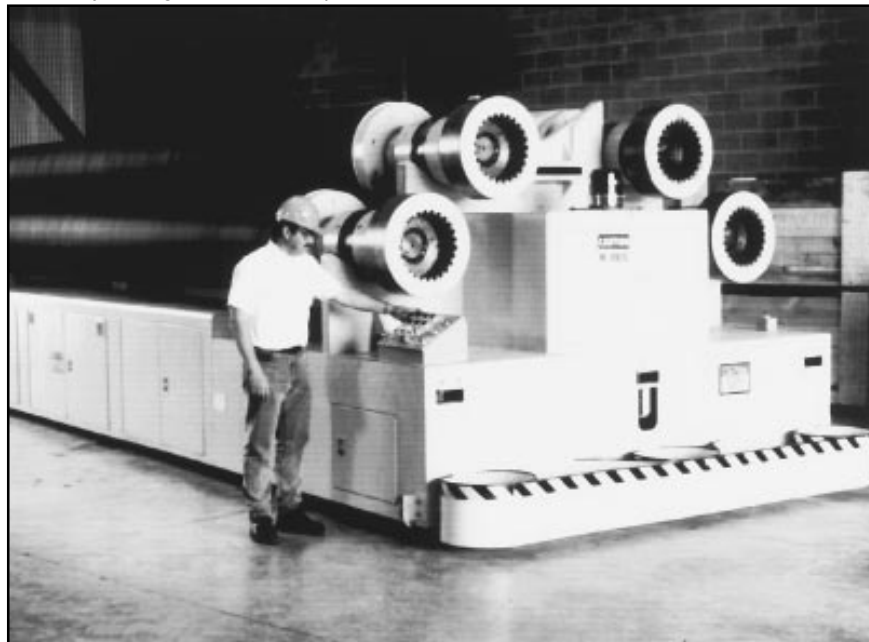
- Scope
- Description of operations
- Equipment specification
- Execution.

The scope provided an overall description of the project, project management details, general project requirements and a definition of supplier responsibilities. The description of operations defined the load characteristics, facility layout and conditions, operating practices, and operational requirements (i.e., throughput rates). The equipment specification defined the major system elements including vehicles, guide path, batteries and chargers, control system, and safety features. Finally, the execution section provided information on delivery requirements, acceptance testing, warranty, terms and conditions, etc. The following sections provide some of the descriptive information defined in the specification.

Load characteristics

Each vehicle was to be designed to carry one reel or up to five spools. Maximum reel weight was 33,600 kg, and a spool weighed approximately 5000 kg. Spool diameter was 64 cm and the maximum diameter and width of a reel were 2.5 m and 6.2 m, respectively. The separation of spool support points was 7.5 m. All loading and unloading was to be accom-

4. Factory testing an AGV under partial load



plished with rotating trolley deck bridge cranes equipped with J-hooks on a spreader beam attachment.

Vehicle features

The two vehicles were to be identical in design and operation. Travel was to be bi-directional, capable of turning on a 9.2-m radius or less if the guide path layout required, and at speeds generally considered safe for the environment and that meet the material movement requirements. Stopping tolerances were ± 2.5 cm front to back and ± 1.3 cm side to side.

Cradles capable of supporting one reel or up to five spools were to be provided. The center reel position was to have a cushioning mechanism to help absorb the loading shock. No flat spots were to be located on the cradles to help avoid improper seating of loaded reels or spools.

At a minimum, the following safety features were required.

1. Mechanical, emergency-stop bumpers at the front and rear of each vehicle

2. Noncontact sensors (IR, sonic, etc.) at the front and rear of each vehicle
3. Side obstruction sensors
4. Emergency-stop buttons on all four corners of the vehicles
5. Rotating amber beacon and audible alarm to activate just before and during vehicle travel.

Two safety features not in the specification but requested and included in the vehicles were:

- A “goal post”-style bumper system to prevent the vehicles from running into suspended loads
- A load sensor, which logically prevented an AGV carrying a reel from traveling into sections of guide path only intended for spool movement.

Guide path and control features

The guide path was to provide an interconnected grid servicing the coaters, finishing winder, supercalenders, reel storage area, and paper machine. A total of eight pickup, delivery, and home locations were to be included (**Fig. 3**):

1. Coater No. 1 reel pickup
2. Home position 1—Opportunity charging location
3. Home position 2—Opportunity charging location
4. Coater No. 2 reel pickup
5. Finishing winder spool pickup
6. Coated reel delivery
7. Spool pickup from, or delivery to, storage
8. Paper machine spool delivery.

The AGV system controller was to receive inputs from controls on the vehicles and at the various pickup and delivery stations, process the inputs, and issue the move commands to the vehicles. Blocking logic was necessary to prevent the vehicles from running into or impeding one another's progress.

General operational (throughput) requirements

The system must be capable of continuous operation 24 h/day and 7 days/week. Expected average and peak daily spool requirements for the paper machine were estimated at 40 and 45, respectively. Similarly for coated reels, the expected average and peak daily production from each coater were estimated at 35 and 58, respectively. While the most common operating situation for the coaters would be to run one coater or run them both in tandem, the AGV system required the capability to support the simultaneous operation of two independent coaters for periods of one to two shifts.

General operating description

The AGV system was required to make five distinct moves:

1. Reels from coater 1 to supercalender/storage area
2. Reels from coater 2 to supercalender/storage area
3. Spools from the finishing winder to the paper machine

4. Spools from the finishing winder to storage
5. Spools from storage to the paper machine.

Each pickup and delivery location was to be equipped with push-button controls unique to that location. A status light was also included to display the status of any active orders (waiting or in-progress) from that location.

Each of the coated reel pickup positions required a "call" and "release" push-button. A "call" request sent an order for the first available vehicle to come to that location. Once a reel was loaded, the "release" push-button directed the vehicle to travel to the coated reel delivery area.

Once the reel was unloaded and clear of the AGV, a "release" push-button located at the coated reel delivery area directed the AGV to return to a home position to await the next order.

The spool pickup position near the finishing winder had the most complex push-button panel. The "call" push-button requested a vehicle to that location for spool loading. Once loaded, three release options exist:

- Release to the paper machine
- Release to storage for unloading
- Release to storage for loading.

A video monitor located at the finishing winder was to display the status of the spool rack at the paper machine. If the AGV was loaded with spools and the paper machine rack had room to accept the load, then the AGV was released to the paper machine. If the rack at the paper machine was full or near full, the AGV could be released to storage for unloading. If the paper machine was in need of spools but there were not enough empty spools at the winder to fill the AGV, the vehicle could be released to storage for loading of additional spools before continuing to the paper machine.

At the location where spools were delivered to or picked up from stor-

age, two status lights indicated whether to load additional spools or unload the spools on the vehicle. Once the loading or unloading was complete, the "release" push-button would either send the full spool load to the paper machine or return the empty vehicle to a home position.

At the paper machine spool delivery location, once a vehicle was unloaded, the "release" push-button returned the empty vehicle to a home location. A "call" request for spools could also be generated at the paper machine if spools were required but none were being sent. This request would send an AGV to the winder and activate a status light indicating the paper machine was in need of spools. The winder personnel would then load the AGV with spools from their area or storage as described earlier and release it to the paper machine.

Order through delivery

The written specification was used as the base document for soliciting firm proposals from heavy load AGV suppliers. The relative differences between suppliers and proposals were evaluated and a supplier chosen. A functional specification was developed by the supplier to provide a greater level of detail than contained in Consolidated's original specification used for bidding purposes.

The time period between order placement and delivery followed the typical pattern of most capital projects. Interaction between Consolidated's engineering department and the supplier's project manager defined the necessary details in vehicle and system design, project scheduling, guide path installation training, spare parts requirements, etc. Once the vehicles were built and operational, acceptance testing procedures were begun.

Acceptance testing

The acceptance testing procedures defined in the specification required two phases: factory and on-site testing.

Factory testing

Factory testing took place at the supplier's test facility. Four spools were delivered to this facility so the vehicles could be partially load tested (**Fig. 4**). The factory testing was to ensure construction compliance with all drawings, test individual components, and operate the vehicles in both manual and fully automatic modes. Representatives from Consolidated's engineering department accepted an invitation to be present during portions of the factory testing.

On-site testing

Upon vehicle delivery, the on-site testing was scheduled. Since construction was quite active in the No. 16 facility and the guide path needed to be clear during the acceptance tests, AGV testing was done during the second and third shifts to minimize conflicts. The on-site testing was conducted in two phases: vehicle functional testing and system performance testing.

Functional testing. A series of checks similar to the factory testing were done on each vehicle to insure the operation of the various components (i.e., safety devices, push buttons, status lights, gauges, etc.). Each vehicle was operated in manual and semiautomatic modes to check maneuverability and guidance capabilities.

System performance testing. Upon successful completion of the functional testing, a system performance test was conducted. This test was divided into two 12-h sessions designed to check items such as system blocking performance, throughput capabilities, and battery performance under expected normal and peak operating rates. A prede-

termined schedule of requests and releases was developed for each day's testing. Since it was not feasible to actually load and unload the vehicles with reels and spools during the testing, it was agreed that each vehicle would carry a load of four spools (approximately half the weight of a reel load) throughout the tests.

The first session of acceptance testing failed due to some flaws in the blocking logic intended to keep the vehicles from running into one another. The acceptance test was rescheduled and the supplier used the remainder of the current testing period to look for and fix any other blocking problems.

The second attempt at acceptance went well, with the AGV system keeping up with the specified throughput rates and the batteries recovering to necessary levels during the available opportunity charging time. The AGV system was accepted and awaited the completion of the remainder of the No. 16 production facility.

Startup and initial performance

Following the paper machine startup, the AGV system startup and debugging process took place over approximately six months, with performance improving steadily during that time. Since the maintenance and operating personnel were both new to the AGV technology, a number of the problems initially encountered were due to not following recommended procedures or the inability to quickly diagnose relatively basic equipment problems (i.e., broken proximity switches). Since the entire No. 16 facility was starting up at the same time as the AGV system, the focus of management's attention was justifiably on matters more crucial than material handling.

To help troubleshoot problems with the AGVs, a log sheet was attached to each vehicle and incidents

documented. This log was invaluable in separating system issues from individual vehicle issues, and also pointed out circumstances common to recurring problems. The supplier's technical support staff was quite helpful in suggesting possible solutions to some problems, and also came on-site when requested to correct some of the more elusive bugs. In one instance, a resistor bank, which was located near the main drive controller on each vehicle, was moved to a more isolated location within the control cavity because heat generated by the resistors was believed to be disrupting the operation of the controllers.

A copy of the operating procedures for the pickup and delivery stations was attached to each of the control panels to help reduce the incidence of operator miscues. A review of system reset procedures was also helpful in solving some "unexplained" episodes of vehicles wanting to run into each other. The operators soon became aware that timely loading and unloading of the vehicles improved system performance and vehicle availability when requested.

In situations where one or both AGVs are down for maintenance or repair, reel and spool flow can be accomplished using (a) the coater unwind shuttle carts to move coated reels back into the paper machine hall and (b) backup carts with a tugger for moving spools from the winder back to the paper machine. Routine maintenance items currently include:

1. Lubrication of casters
2. Antennae adjustments
3. Providing proper air pressure in the bladder which maintains the tractive force on the drive wheels
4. Periodic battery rotation to provide equalizing, full cycle charging.

Battery-related problems have been minimal, with an occasional

"unplanned" battery change required due to charge depletion. This problem is related to how quickly the operating personnel load or unload an AGV after it arrives at a pickup or delivery location. In retrospect, one or two additional opportunity charging stations may have been warranted.

Overall, the application of AGV technology to reel and spool handling for the No. 16 papermaking facility has proven to be successful. As with any complex piece of automation, a learning curve must be expected, and Consolidated's experience was no different. Maintenance and production crews have become better educated in the system operation, and occurrences of problems are much more infrequent and manageable. When recently asked to compare the AGV approach to reel

and spool handling with systems used before the No. 16 project, one coater employee emphatically replied, "No more tuggers!"

Conclusion

The intent of this paper was to develop an awareness in individuals considering using AGVs in heavy load applications of some of the issues and expectations important in such an undertaking. The experience of Consolidated Papers, Inc. with the justification, specification, installation, and operation of such a system has been a valuable learning experience from the initial proposal forward. Reviewing this experience would be beneficial to those considering similar applications of AGV technology.

AGVs are a feasible alternative for paper reel and spool handling. Depending upon the facility layout, size, and handling requirements, the unique characteristics of AGVs can provide a reliable and economical approach to heavy load material handling. ■

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