

Allen Skaja: [00:00] Today we're going to talk about Robotics Coatings Applications. This has been a very, I guess, big area of application for fast production rates. Contractors have been using this since 2008 or 2009. In just the past couple of years, some contractors have taken into the next level and now can do it on steep slope pipelines.

[00:39] This is relining the interior surfaces. What are we saying is robotics coatings? This is primarily for the internal pipe it's where we can do jobs at a much faster rate, much faster application, and they can get in and get out within half of the amount of time usually of a typical coatings job.

[01:12] It's not necessarily 100 percent robotics. It's using equipment for automation so it's not where they have people in there doing the manual labor. They're using equipment to increase productivity. They can do water jetting, abrasive blasting, as well as the coating application.

[01:42] When I say robotics, it's not necessarily like a machine that is used via a control stick or...it can have a winch system that is controlling it by a specific rate and not necessarily using a joystick to move it left or right, or that type of stuff.

[02:17] There are some equipment that have been developed for that but I just don't know how fast the production rates will be. They're very new equipment.

[02:31] What we're talking about today is just the internal linings of pipes and there's equipment that can go up to a 32-foot diameter so that pretty much takes care of most of the infrastructure in reclamation. There's only a few pieces of infrastructure that go above a 32-foot diameter.

[02:59] There's a few things that are beneficial for the robotics application. I would say number one, it is safety. If you have a steep incline and you have to be on ropes access, it becomes very challenging to have any sort of high productivity when you're working from a platform and you have a winch system that can lower or raise the platform.

[03:30] If something happened where there was an emergency situation, having that slow control winch system, you may not be able to get out on time or it may take more effort to get the person to safety. Using the robotics applications, we're putting fewer people in harm's way. It's a much safer application procedure.

[04:03] When we're talking about hazards, it's not necessarily if someone got injured on the job, but we're also talking hazardous environments such as particulates and solvents.

[04:20] The abrasive blasting procedure, we take a step back and eliminate or reduce the number of people working or exposed to the hazardous material, whether it's the abrasive blasting process itself, or the existing coating system that's on that structure so if it was coal tar enamel, lead-based paints or what have you.

[04:48] The other thing too, is we have proper airflow and continuous monitoring, engineering controls to force air through the pipeline so we can control the environment. If employers had to, they can still supply their respirators.

[05:19] I would say the biggest driving force to find safer methods was this Xcel Energy, Cabin Creek fire that occurred in 2007, where even though the contractor was using high percent solids epoxies. They were using MEK solvent to clean their equipment and they were atomizing all this solvent into the space.

[05:45] There wasn't adequate ventilation and a fire had broken out. There was poor safety planning and there was no emergency response plan. It was very unfortunate but five people died inside that penstock due to being trapped above the fire and had no way to escape.

[06:13] Automation greatly reduces the risk here, that is I would say the number one benefit. Second benefit is, there's high productivity, it benefits the contractor as well as reclamation because we can have shorter outage windows to complete the work and what that equates to is dollars.

[06:42] We could be generating power or doing water delivery. It's a benefit for both the contractor as well as reclamation. That's compared to a conventional job. The photo here is a conventional repair method at Grand Coulee, this was the Third Power Plant. That penstock is around 40-45-foot diameter, somewhere in there.

[07:16] You can see me standing in the foreground of the scaffolding structure, which is on a winch system and they lower this down the steep portion of the penstock. There's people standing...Would be doing abrasive blasting or surface prep as well as coating application off of this platform.

[07:42] Because I was not rope certified, I would not have been able to go on that scaffolding while it was being lowered down. It is very time-consuming because as you can see if you had to move between the various levels of that platform, that scaffolding platforms, it takes to do that as well as moving your equipment, your hoses, etc., to the various platforms.

[08:20] The biggest advantage here is if you used robotics, it's a lot less time-consuming. Here's a case study that we did. I was basically hired as a consultant for the Central Arizona Project to evaluate the coatings and the process for the entire job. When I first reviewed this job I thought, man, 100,000 square foot, 12-foot diameter, 2,500 feet in length.

[08:54] I thought with the slopes, that would require this ropes access as well as a scaffolding system, and they wanted only a 90-day outage. I've told them, man, there is no way you can get that you can get this job completed within that 90 days, and the contractor was on the phone, and he said, "We plan on using robotics application and we have done similar jobs in less time than this."

[09:37] They reassured their client that they could get this job done with everything. With the drop in elevation in the slopes, they guarantee that they can get this job done, and I was skeptical but in the long run, the contractor was right. They got the job completed in the 90-day outage and with all the complications and various terrain of this environment. Here is the Mark Wilmer Pumping Plant and...

[10:19] Is there an arrow that I can show?

Audience Member: [10:22] It's so tiny.

Allen: [10:23] They can see the arrow? OK. Here, you can see the various levels. There's access points right above the power plant, but water gets pumped all the way up here to the top of the mountain. I don't remember what the mountain name is. It's Buckskin mountain, I believe.

[10:49] It pumps all the way up there. There's 824 feet change in elevation. The existing condition...This was lined in the 1980s with coal tar enamel. It had the really good coal tar enamel, but yet we had coating delamination almost throughout the entire length of the pipe. This was in really bad condition.

[11:22] We're not a hundred percent sure why the coating had failed when three miles down the road at Parker Dam, that lining is the original lining. It has been in place since the 1940s. That's 70 years, whereas this application of coal tar, 1980s. It had about only a 35 years' service life.

[11:47] The relining plan...This is Hartman-Walsh that won the contract for this. They planned on using robotics. They were going to use water jet robotics to remove the coal tar enamel, get it down to bare metal, use an abrasive blasting to get to near-white or white metal using the modified commercial equipment. Then they had a in-house design robotic coating machine, a spin coater.

[12:31] They had proprietary methods for working on a steep. I was never allowed to go inside while they were doing the coating application. Again, I don't have rope certification. You're limited to what you can do on steep slopes if you do not have those certifications.

[12:57] They came in with huge, huge equipment. I have never seen equipment this large before. It was just pretty impressive, very large air compressors. They had very large generators, dust collectors, pressure pods, vacuums, air dryers. I don't think they needed the air dryers, but they needed the air conditioners.

[13:24] They did this work starting in June and went through August. If you've ever been down in this area during those time frames, you're looking at a 110 to 115, even 120-degree Fahrenheit temperatures. The actual workers enjoy going down into these containments, the confined spaces because it was at least a 20-degree temperature drop.

[13:52] The winch system is what made this whole thing work, especially on the steep slopes. They could control the rate of the equipment, whether they were lowering it or bringing it back up. It was adjustable. They could control the rate.

[14:20] I'm assuming that the rate on the abrasive blaster was much slower to get that near-white metal blast, compared to the coating application equipment which is high productivity. The water jetting, they could do up to about 100 linear feet in a day of a 12-foot diameter. You're looking at about 3,600 square feet per shift.

[14:51] They actually ran two shifts per day. They would run two eight-hour shifts per day. That meant 16 hours a day, they were working. It is a very fast method to remove coal tar enamel, especially when it's degraded coal tar enamel. It's effective at moving the residual oils out of that coal tar. It eliminates the hazardous dust that anybody would be exposed to.

[15:30] You didn't get coal tar dust on your employees because it was wetted down. In the end, the coal tar debris was the only source of any hazardous waste that they had to get rid of. I don't know the facet. The coal tar ended up being actually disposed of hazardous waste because once you test, you basically determine whether it's hazardous or not by the [indecipherable] out of that material.

[16:15] During the abrasive blasting process, these rates were much slower. They were about 50 linear feet per shift, so about 1,800 square feet per eight hours. It's still much faster than if they were to do this manually.

[16:36] If you had one abrasive blast person in there, suited up on a scaffolding system, tethered off on ropes axis, I would be surprised if they could even get half of that surface area blasted in eight-hour period.

[16:59] It's so much faster. It reduces that manual labor. I would say of the entire process, the abrasive blasting is the most labor-intensive if you were to do it conventionally. It wears on a person. They can probably work straight for about two hours before they're just so exhausted that they have to get out.

[17:32] Not only that, but they're in a full blast suit and blast helmet. If they're working in 90 to 100-degree temperatures, I just can't imagine the heat exhaustion. It's much safer to have them monitoring equipment to do the blasting process. Again, because the coal tar was removed, now, they're only exposed to the blast media dust.

[18:06] Moving on to the coating application, we don't have a close up of the actual robot. The reason for this is because it is an in-house design. We didn't want people being able to see how Hartman-Walsh built their robot. They use 100 percent solids epoxy, so solvent-free.

[18:38] This was the exact same system that Cabin Creek fire, they used, but here it's different because they used, Hartman-Walsh used hose bundles, a plural-component hose bundle, so each component is in a separate line all the way up to near where the robot is before it gets mixed.

[19:04] It goes through a couple mixed manifolds, and then it's a single feed line to the robot. When they had to clean out their equipment, it's basically, they took the mixed manifolds off and their little whip hose, 25-foot whip hose.

[19:25] They took those off and completely replaced them after every shift or every shutdown. Then, they took the nozzles off, took those out of the containment, and they could put those on a five-gallon pail of cleaning solvent, and then just clean the guns and the nozzles.

[19:46] That's the picture on the left. The picture on the right is where they had a trailer set up with the pumps. So they took the drums of the material, component A, component B, and they used the pump, and they pumped all the material through those hoses to the robot.

[20:15] So there was no additional pumps inside the containment. Now, like I said, they went through a lot of material in a very short period of time. Per day, this is two shifts. They could get 500 linear feet down in a day, 1,800 that was the fastest they were able to go. This was on

steep slope again. It was not on flat pipe. You could imagine maybe even faster on a shallow incline.

[21:00] It's just amazing how fast they can do this. Again, this is a close up. We didn't want to get too close to show how the robot's setup. They can pop material 800 to 1,000 feet in length. From where the pump is, they can pump all that material up to 1,000 feet. Already mentioned the mix manifolds and how they did their production.

[21:39] It was a much safer means and methods approach to applying the coatings at Mark Wilmer. Here is the final coating product, 60 mills. They were within a couple mills throughout any portion of this pipe. After the one-year inspection and they had zero defects, that is truly impressive because we've done projects where we have a hundred spots that they have to go in and fix.

[22:19] Just having it after one year and no defects is very impressive. It's higher quality end product. That's the end of the CAP project and how they were able to do that whole project in 90 days. There's some other equipment that has come out on the market in recent years where it's just neat watching the progression and how companies are developing new technologies.

[23:00] There's the upper left is a small diameters robot where they put it inside the pipe, and then they can pull the hoses and move the robot at a certain rate to get a blasted profile on a small diameter pipe.

[23:24] The center photo is a centrifugal blast unit where it can be either horizontal or vertical. In this case, it's vertical going up the side of a tank. You have a two-foot wide path, and they centrifugally blast clean this surface.

[23:45] Again, you get a high productivity rate. It's all self-contained. There's vacuum hoses sucking up all the dust and whatever the old coating system is.

[24:01] Then the two lower photos, these are blasting units. The one on the left has a camera. It's a blast unit that is coupled to a magnetic crawler. Both of these are magnetic crawler units. They can abrade the glass to seal a surface, and everything is controlled by an Xbox controller.

[24:37] We have various techniques now where if you have to do spot repair on a vertical or horizontal surface or even in the pipe, it looks like they might be able to accommodate those situations.

[24:56] Other technologies, there's various levels of coating machines, designs. One is called ROI360. Then there's another one called Robotic Pipe Repair as well as this PRD company. There's various techniques and styles.

[25:25] I'm going to show you just a couple videos here. Now, this is for the exterior of pipe joints. This is very slow. There are techniques, if they weren't doing a vacuum blast, that you could go much faster. It's what is potentially out there for the future.

[25:48] We have a couple products where we're doing the exterior of pipe. Maybe this is the next methods for doing these coating repairs. I could envision seeing this now on a system where it's on an extension system. It would also move in a Z-direction, not just circumference.

[26:19] I don't know what the future may hold. This is very interesting technology. It looks like it's very fast at coating application. I would assume that you could do something similar for the abrasive blasting.

[26:35] Now we have the benefits for the contractor. The list is quite extensive. You're reducing the exposure. You're reducing the number of employees in the confined space that may be on ropes access. You're reducing that fatigue of each employee. You're having the equipment do most of the heavy lifting.

[26:59] You have improved surface cleanliness, consistency, as well as coating thickness control. Fewer holidays, less touch-up work, less fuel consumption because you're doing this at a much faster production.

[27:18] You have less, or reduced, amount of PPE purchasing, reduced blast media, as well as coating material waste. You're fast to return to service. They're moving on to the next job.

[27:39] For reclamation, I can see the benefits. This type of application, you have less exposure to employees and contractors, so less hazardous conditions. You have a higher-quality end product, so fewer holidays that may develop. You have less disturbance to the pipe interior. You have lower levels of scaffolding or equipment, people mobilization, short-outage window.

[28:15] This is the big thing. Getting that work done and the plant back in operation, reduce safety liability, as well as reduce labor costs. Even though we talked about the contractor costs, we also have employees monitoring these contractors. There's a safe savings there as well.

Presenter: [28:45] What is field EIS or Electrochemical Impedance Spectroscopy? Essentially, it is a frequency dependent application of Ohm's law and the value that we get from running the test that is most important to us is called the impedance magnitude. That is derived from the resulting voltage and current data that we get from the EIS test.

[29:12] Impedance itself is a measure of how much a circuit is resisting current or in our case, the flow of electrons through the coating. When we get large impedances that means that the coating is providing a greater protection against corrosion.

[29:35] Whereas, smaller impedances can tell us that the coating is allowing a lot of electrons to flow through and is providing poor corrosion protection. Field EIS again is a quantitative approach to estimating the remaining service life of a coating. We use field EIS on a defect-free linings.

[30:08] When we get impedance values that are above 10^8 ohms at 01 hertz, we would consider that to be a good coating that is still providing good protection. The figure just shows our basic field setup. We use a laptop. The potential stat itself three different electrodes and then can't really see them, but we have three test cells that are adhered to the pipe long.

[30:41] Why would somebody want to use field EIS testing on a structure? Again, it is a method that can complement visual inspections. While a visual inspection qualifies coating damage that we can see, EIS can quantify on-damage coating performance. Again, this is a test that we only run on visually undamaged coating.

[31:11] Just because the coating looks good doesn't necessarily mean that it is performing well. It is a method for us to make decisions based on hard data. We can use it to develop threshold for coating maintenance for a particular structure. If we can't re-coat the entire structure, we can use it to identify only certain areas that should be re-coated, that are in the most need for that re-coating.

[31:46] In addition, we can also use it on newly coated structures before they go into service to ensure that the coating that was justified, is performing as expected. In these situations, we wouldn't recommend doing it on every single coatings job.

[32:06] Maybe just on those where we have some doubts about how the coating was applied or possible high profile situations where the coating needs to be in excellent condition right after application.

[32:22] Again, EIS can be used to test for remaining service like this slide. I'll just explain a little bit about how we setup the test and what it actually involves. We use temporary cups that are glued to the coating itself at regular intervals throughout a pipe or a siphon. Those cups are filled with an electrolyte solution. Then we perform the test.

[32:57] The test can take between two to five minutes, depending on the frequency that we run the test down to. When we first started doing these EIS surveys, we would run the test from 10^5 to $10^{.05}$ hertz. That would take about five minutes. In our more recent surveys that we've done, we've only been running it down to about 01 hertz.

[33:27] That has shaved off about two to three minutes from our test time and we still get the same useful data just in a shorter test time. The setup is really the most time-consuming part of doing an EIS survey, and it takes about one to two days depending on the number of test locations.

[33:52] What we have to do is first, clean my area where we want to do the test. Apply the adhesive to the cups and attach the cups to the surface. The adhesive needs a few hours to dry and then we can come back and fill the cups with our electrolyte solution.

[34:12] Now, depending on the coating and depending on how saturated with water it already is, will determine how long we need to leave that electrolyte solution in the cups before we can actually run the test. If it is a newly applied coating or if the structure or feature had been dewatered for many days, we might need to leave the water in the cups to saturate overnight.

[34:42] Whereas, if the structure had just been dewatered earlier that day, we don't need to leave the water in the cups for F_1 . It is only after the coating is re-saturated that we can then perform the test. Again, that will take about two to three minutes. The test is performed at an open circuit potential across many frequencies.

[35:10] You take five data points per frequency over a range of frequencies as shown in the table. One of the first EIS surveys that we did was the interior of a large siphon. We were able to collect data at 42 pipe locations and we tried our best to get one EIS test per every four pipe segment. The results that we get are in the form of what is called a Bode Plot. That is the figure shown here. Every curve in this figure is one data set for one location.

[36:00] The Bode Plot shows the impedance magnitude versus the measurement frequency. Again, we are most concerned with the frequency that is the very lowest. In this case, we are concerned with that very, very first data point at 005 Hertz.

[36:18] We would like to consider that impedance magnitudes that are around 10^8 ohms and higher are where the coating is showing capacitive behavior, and it is performing well at preventing corrosion. Anything below 10^8 into 10^7 ohms and below, we would consider the coating to be performing like a resistor. It is allowing a lot of ions and water to flow through the coating.

[36:59] We can relate this to whether or not these locations need to have the coating replaced by saying that anything above 10^9 ohms, the coating is good and shouldn't be replaced. Whereas, around 10^8 and below, we would recommend replacing the coating in those locations.

[37:24] What does this Bode plot tell us about exactly where in the siphon or the pipe the coating needs to be replaced? If we plot the data in a different way, which is impedance magnitude versus pipe segment number where we collected that value, we get this profile of the entire length of the pipe and exactly where the coating is performing poorly.

[37:56] At this particular example we recommended that the coating is replaced on segments 20 through 90, and then at segment 200. If we had the pre-service values for this particular structure -- that is if we had been able to run an EIS survey before it went into service for the very first time -- we could have actually calculated a degradation rate per pipe segment.

[38:33] Another way that we can display this data that complements the previous figure is to use a 10-percent probability quad. We would recommend re-coating if the statistical analysis average is less than the threshold value, which we've identified to be 10^8 ohms.

[38:56] In this particular case, we have two linear fits that we ran. The first one, the one that bisects the probability curve in two places, that is where we did the simulation for all the data, throughout the entire pipe. It is not linear, so that suggests that there is a bias in the data. Therefore, there is non-uniform degradation occurring in the pipe.

[39:29] That is similar to what we saw in that previous figure, where some portions were much more degraded than others. Then our second line that we fit was only to the good data. Since that is a linear fit, we can assume that that portion of the pipe is degrading, or the coating in that portion of the pipe is degrading uniformly.

[40:00] In conclusion, we found that the majority of the pipe in this case is in good condition, and the full relining is only needed in the select sections that we pointed out in the previous figure, and in the ones that came out in this probability plot.

[40:20] Some other ways we can manipulate the data are by correlating it with the pipe profile. If you see the inset in this figure, that is the profile of the siphon. The siphon's elevation changed about a thousand feet. This profile shows that change.

[40:45] What was interesting that we found in this particular EIS survey -- it hasn't matched this well for other surveys that we've done, but just as an example here -- we found that the degradation of the coating

closely followed the siphon's profile. Ignore that red line, that is just a five-point adjacent averaging that we did for all of the data.

[41:15] You can see that where the siphon profile changes quite drastically, so does the impedance magnitude values. That is for areas where the elevation is increasing, and also decreasing quite drastically. We can use this type of correlation to figure out failure mechanisms of the coating. For example, we are assuming here that where the areas of elevation change exhibited more damage.

[41:56] That could have been due to sediment scouring, or different flow rates. This could help us when we were specifying coatings to replace this coating system with, because we can say, "OK, there might be some sediment scouring here, maybe we should replace it with a more abrasive resistant coating."

[42:20] Whereas, in other portions of the siphon, we're not really seeing that, so we might not need to use those types of coatings in those areas. In summary, field EIS testing reveals the corrosion protection ability of visibly defect-free lining. We can use it to estimate the remaining service life or decision making using low-frequency impedance magnitude versus location and probability plots.

[42:57] We would also like to announce that we have a technical publication on field EIS -- how it works, and how it can be beneficial for you or your facility. That is now available through us, I believe it's on the website. Thank you. Are there any questions?

[43:21] [off-mic question]

Presenter: [43:25] Resources for both my presentation at the bottom, and Allen's robotic presentation, the TSC's materials, and corrosion laboratory staff are also a great resource if you have any further questions. This is the updated list of our current staff.