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MEMO ON DEVELOPMENT OF QUALITY ASSURANCE TOOLS FOR KBS-3V EMPLACEMENT WORK AND GAP FILLING

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Contents

1 INTRODUCTION

The memo describes development of methods to ensure the overall quality of the bentonite buffer that surrounds the spent fuel canister, in the vertical deposition hole of a KBS-3V-type emplacement geometry.

The final disposal facility to store the spent nuclear fuel from existing power plants in Finland will be located in Olkiluoto, approximately at the depth of -420 metres. At this level are also the demonstration tunnels used to test the final disposal techniques and this quality assurance equipment.

The bentonite buffer consists of a bottom disk-shaped unit located below a spent fuel canister, five ring blocks surrounding the canister and four disc blocks installed above the canister. The buffer is emplaced using a buffer installation machine (BIM). The buffer needs to be positioned correctly and have a certain density in order to function as expected. The gap between buffer blocks and host rock is to be filled with bentonite pellets.

The main aim of the work described in this document was to define quality requirements for buffer emplacement work and gap filling, as well as designing and testing the quality assurance equipment and control procedures.

2 FEASIBILITY STUDIES

This chapter presents the results of the feasibility analysis on the methods that could be suitable for quality assurance of the buffer manufacturing process through to its installation in the deposition borehole. The methods with which the quality requirements for assembling the bentonite buffer can be achieved are also introduced.

In order to test the measurement and monitoring approaches proposed for use in assuring placement consistency and overall installation quality assurance a comprehensive series of full-scale tests were conducted. It should be noted that most of these tests involved use of concrete mockups of the buffer component that represent a full-scale simulation of the installation process and measurements. The use of concrete rather than bentonite blocks was undertaken in order to allow for repeated installation and movement cycles without risking damage to buffer segments or inducing difficulties associated with prolonged exposure of the bentonite segments to the atmosphere (cracking, desiccation).

Buffer block dimensions and tolerances used:

- Outer diameter 1650 ±1mm
- Inner diameter 1070 ±1 mm
- Bottom block height 500 ±1 mm (1 pc)
- Ring block height 960 ±1 mm (5 pcs)
- First block on top of canister; height 400 ±1 mm (1 pc)
- Second and third block on top of canister; height 800 ±1 mm (2 pcs)
- Top block height 500 ±1 mm (1 pc)

2.1 QA1: The integrity of the Buffer Blocks during the Installation Process

2.1.1 Background and Motivation

The goal of this activity is to ensure that a bentonite buffer block will end up, as an intact unit in its target position in the deposition hole. This is a key goal as a fracture in a bentonite block may decrease the strength of the block so that it breaks into pieces under its own weight or because of the stresses induced by buffer block installation machine (BIM) handling the block. As a result the inspection of the blocks from the time of manufacture through to their placement will be a key process in terms of ensuring quality is maintained

2.1.2 Studied Approaches

The most promising technologies for the surface inspection of manufactured buffer blocks are machine vision (Photogrammetry), close range laser scanning and white light measurement technologies.

Machine vision is based on taking ordinary or high resolution photographs and analysing and processing them then with a computer or by human review. Various illumination techniques such as structured laser illumination, side lighting etc. can be used to tune the technology to various measurement tasks.

Close range laser scanner scans the surface from shortish distance of 50-100 mm. Laser scanning area from one position examines an area of approximately 100 x 100 mm and one partial scan takes approximately one second. The scanner produces a 3D point cloud which can be processed further to generate a surface model. The surface model can then be compared against the CAD design and the measurement data which was gathered at the factory QA to see possible deviations on block's surface.

In white light technology the measuring device projects a light pattern on the surface under inspection, photographs it and then produces a point cloud based on the acquired data. One measurement covers area of approximately 500x 500mm taking less than a second to complete. Depth of the measurement field is 270mm. Measurement distance is 700 to 800 mm.

2.1.3 Recommended Approach

After review of the options for block inspection listed in section 2.1.2, both machine vision and white light technology were identified as good candidates for block inspection. They are accurate and fast enough and the required engineering effort is not overwhelming.

- Machine vision would probably provide the lowest cost and smallest engineering effort, thus is identified as the most attractive approach.
- White laser scanner would also perform the inspection task and it could be used to measure the drilled holes, but otherwise white light won't provide any remarkable benefits compared to machine vision.

Close range laser scanner is not feasible due to the small shooting area and especially due to the long data analysing time, which cannot be cost-effectively compensated by increasing the number of sensors used.

2.2 QA2: The Position of Individual Bentonite Blocks and the Assembled Buffer.

2.2.1 Background and Motivation

Two things motivate tracking of the positioning quality of the deposition hole's buffer assembly. The first one is a need to guarantee that the canister can be installed in the buffer assembly and the second is that the gap between the host rock and the outer surface of the buffer blocks has to be aligned so as to allow for pellet filling to be accomplished.

The minimum clearance between the inner surface of the ring shaped bentonite buffer blocks and the copper canister is 9.5mm [(1069mm-1050mm)/2]. This takes into account the manufacturing tolerance of the blocks but assumes a zero deviation tolerance in the buffer assembly.

The width of the outer (host rock to block) gap has to exceed 25 mm to allow proper filling with pellets.
Hence, alignment of the individual blocks in respect other blocks and the verticality of the whole buffer structure are critical parameters canister. This tight tolerance is the motivation for tracking and

preferably also preventing the possible tilting of the buffer assembly and also the need to measure how close to the target XY-coordinate each block is placed. Because there is practically no vertical asymmetry in a bentonite block (the height of one block is the same no matter where it's measured) the only sources for tilting are:

- a foreign object on the surface to which the next block will be lowered (referred to as touch point for now on). This is the reasoning to check that the touch point is clean enough.
- A faulty leveling process at the bottom of deposition hole. This will mean that the bottom of deposition hole might not be in horizontal alignment.

In addition to block-related alignment issues, if the whole buffer is not correctly positioned in XY-plane the gap between the host rock and the block differs from the planned. This may create problems while filling the gap with premeasured amount of pellets. Finally, if the borehole itself is not within the verticality specified, the blocks and gap may not meet the clearance specifications.

The sub targets of the QA2 are:

- To ensure that the buffer and blocks are vertically aligned with an accuracy of ±0.01 degrees. From this two sub tasks can be derived:
    - To ensure that every block sits correctly on top of the block below and the first block at the bottom of the hole.
    - To ensure that block's installation surface is clean enough so that the buffer structure won't start tilting after block is lowered.
- To ensure that the whole buffer and each block are placed within ±1mm tolerance to the planned XY-coordinate.

2.2.2 Measuring the pitch and roll angles of assembled bentonite block to ensure that the buffer and blocks are aligned vertically

The first task is to track the angle of assembled blocks.

Background and Motivation

The buffer structure should be vertically aligned to allow successful canister installation and pellet filling as described in chapter QA2: The Position of Individual Bentonite Blocks and the Assembled Buffer.

Studied Approaches

Basically it is quite straight forwarded to measure the vertical and horizontal alignment of the installed bentonite block. The following three methods were evaluated:

- Using the laser tracker which already measures the 3D coordinates of the container during the block lowering,
- using a precise dual axis inclinometer mounted to the container or gripper and
- using laser distance meters mounted to BIM's frame to measure the distance from the BIM to the lowered bentonite block.

Recommended Approach

Because the laser tracker will probably be used as BIM’s 3D-coordinate measuring instrument, using it to also provide the as-placed angle of the bentonite blocks comes at an almost zero cost and effort increment. The downside to its use is that the measurement is not direct but assumes that block’s angle can be derived from container’s angle. The laser based distance measurement unit mounted on the rotating fixture on BIM’s frame produces accurate and directly measured angle information. It requires some additional mechanics and support electronics but those will probably be needed anyways for the QA3 and QA4.

The alternative of using a separate, state of the art inclinometer doesn’t provide any advantages compared to the laser tracker. Neither inclinometer measures the block’s surface alignment angle directly and hence an additional monitoring sensor doesn’t provide better accuracy than other approaches.

The recommended approach is therefore to combine the data that laser tracker already provides with the direct measurement with one laser distance meter mounted on the rotating fixture.

2.2.3 Ensuring that block’s touch point is clean enough to ensure that the buffer and blocks are aligned vertically

The second task is to check that the touch point surface on the previously lowered block / bottom of the hole is clean before the next block is lowered into the hole.

Background and Motivation

The buffer structure should be vertically aligned to allow successful canister installation and pellet filling as described in chapter QA2: The Position of Individual Bentonite Blocks and the Assembled Buffer. Checking that the touch point surface (the upper surface of the previously assembled block(s) or the bottom of the hole) is free of foreign items is relevant because they are the most probable reason for tilting. The tight manufacturing tolerances of the bentonite blocks should eliminate deviations in size and shape as a cause for misalignment of the blocks. Although unlikely, it is possible that a bentonite block could develop height asymmetry during the transportation/storage phase. This potential source of block deformation has not yet been assessed and will only become evident when a substantial number of block movements and placements have been accomplished.

Studied Approaches

The following table (Table 2-1), describes the key aspects and cost estimates associated with two candidates studied as potential methodologies for undertaking of inspections of touch surfaces.

Table 2-1. Key technical features and estimated costing to implement Machine Vision and Laser Scanning

Parameter	**Machine vision**	**Laser scanner**
Pixel resolution at maximum measuring distance of 12 meters	5Mpix:0.80mm , 30Mpix: 0.33mm (requires motor zooming) accuracy up to tests	2mm (3D –coordinate accuracy)
Measurement time	1-2s	1-2min
Analyze and data transfer time	5-10s	4-6 min
Design effort of support electronics(1-5) 1: very small, 5 very big	2 (excluding possible structural illumination)	1
Design effort of required support mechanics(1-5)	2 (excluding possible structural illumination)	1
Design effort of the software (1-5)	2 (excluding possible structural illumination)	2-3
Sensor cost	5k€ (5Mpix) 15€ (30Mpix) + analysing computer per each camera (2-3k€) + motorised zoom object 2-4k€ 9-22k€	35-60k€, depends on the model
Cost of support electronics	0.5 -1k€ (excluding possible structural illumination and automation of the rotating fixture)	0
Price estimate for the required rotating fixture automation HW (motors, actuators, sensors, controller). This is can be shared with laser distance meters	7,5 -12 k€	
Cost of support mechanics	< 500€	< 500€
Probability of success	95-99%	95-99% but in order to meet the maximum available measurement time of 60 s specified, the probability is less than 10%

Recommended Approach

It is quite clear that machine vision is the only feasible solution from the studied approaches unless the current time available for inspection of each block is relaxed to 4-6 minutes.

Additionally, in order to be able to operate at varying measuring distances within the deposition borehole without losing resolution, a motorised zoom lens is required. Particle observation accuracy can probably be boosted by adding a structured laser illumination to highlight deviations in surface smoothness. The same machine vision system could be possibly used also for other QA tasks such as the gap measurement (between the host rock and buffer) and analysing the pellet formation created in gap filling.

2.2.4 Ensuring that the whole buffer and each block are placed within ±1 mm tolerance to the planned XY coordinate.

Background and Motivation

The motivation and background to measure the X-Y coordinates of individual bentonite block and the whole buffer were explained in the beginning of Chapter 2.

Studied Approaches

There are a few different approaches available to monitor block placement tolerances. These include machine vision, laser scanner and using the data achieved from the laser tracker which is already used during the installation process. The accuracy of each of these methodologies is summarized in Table 2-2.

Table 2-2. Comparison of the accuracy of Laser Tracker, Machine vision and Laser Scanner

Parameter	**Laser tracker**	**Machine vision**	**Laser scanner**
Achieved accuracy	100-400 µm	3-5mm	2-3mm
Type of block's position measurement	indirect (via container top)	Direct	Direct

Of the methods studied, only the laser tracker can meet the target accuracy of ±1 mm (REF?). Other methods such as machine vision may be used as a support measurement but they are not able to give information other than that the installation is totally out of the desired accuracy target.

The complication with its use is that the laser tracker is also used to guide the block to the correct XY coordinate during the lowering process. Making QA measurements of the device with the device itself is usually not the preferable solution. However this can be overcome by tracking a known 3D-coordinate and comparing the results to premeasured datum.

There are two different ways to accomplish this type of positional comparison using the laser. In the first, a reference reflector can be mounted on BIM's crane at the known 3D coordinates (in BIM's local coordinate system). Then, by measuring the position of the reference reflector it is easy to observe the accuracy of the laser tracker. The only restriction is that there cannot be any moving parts between the reference reflector and the laser tracker or the reliability of this procedure is endangered. The other method is that to compare the factory measured, 3D location of each container mounted reflector in container's local coordinate system to the data provided from the laser tracker. Depending on the desired reliability level a separate reference reflector may or may not need to be mounted on the crane.

A further potential issue is that the laser tracker is not measuring block's XY- coordinate directly but via the container mounted reflectors. This approach assumes that we know how the block is positioned in the container. That position is measured at the factory but there is always a risk that the block was dislocated during the transportation. To be able to detect that and actually also compensating for it, the position of the block in the container can be measured just before BIM lowers the block in to the deposition hole. This measurement can be accomplished as a part of the block's integrity test either with machine vision or by using 2 laser distance meters.

By using a reference reflector and block’s position measurement technics, the error sources are reduced to the untracked movement of the bentonite block in the container while the BIM handles the block or when the block is released from the container at the end of the lowering. The error source (block movement) is unlikely to occur because the container holds the block in place using a vacuum at block’s upper surface. It is possible that the block could move when it’s released from the container at the end of the lowering. The probability of this occurring can be reduced to very small level by utilising two tactics. The first one is that the block is lowered to the touch point very evenly so that block’s pitch and roll angles are within 0.01 degrees compared to the angles of previously lowered block. The second tactic is that the block won’t be released until it’s fully supported by the bottom of the hole or the previously lowered block. This can be detected with the force sensors mounted to each of the ropes which holds the gripper (which holds container carrying the block).

Recommended Approach

The recommended approach is to rely on the accuracy of the laser tracker, monitor its accuracy and minimize the risk of untrackable block movement in the container. Machine vision can be used as a supportive method to identify major failures.

2.3 QA3: The width of the gap between assembled block and the host rock.

2.3.1 Background and Motivation

The buffer installation including the gap filling is planned prior to the actual buffer installation occurring. Planning for dimensions, alignment and gap volumes are based on the 3D model of the hole, generated by laser scans undertaken at the time of its excavation. Then, by measuring the gap between the host rock and just assembled block during the buffer installation process it is possible to ensure that the installation process is going as planned.

The accuracy target for the gap width measurement between the rock and the installed buffer is 5mm. It is important to recognize that borehole drilling will induce ridges and grooves in the wall and as a result the surface of the host rock is not smooth, and horizontal roughness of 10mm could be expected to exist.

2.3.2 Studied Approaches

The gap width can be measured either at the gripper level before releasing the bentonite block from the container or it can be measured from the top of the hole with sensors mounted to BIM’s frame. In the first method one downward looking laser sensor is mounted to each of three pads of the gripper. The main purpose of the pads is to take support from the walls of the hole during block’s slow final positioning and lowering phase (Final lowering phase starts 15-25mm above the planned touch point). Placing the sensors on the gripper would provide close range distance measurement, but the bentonite block is not visible to the sensors. This is because, due to requirements associated with the vacuum-based lifter, the outer diameter of the buffer block transport container is 16mm bigger than the outer diameter of the bentonite block. A different type of, but also gripper mounted sensor could be used to measure the horizontal distance from its mounting point to the host rock to provide the gap width. However this is still an indirect measurement and would also require a wide beam to compensate the surface roughness of the hole.

Placing the gap width sensor or sensors on the BIM’s frame or crane instead of on the gripper enables a direct measurement and compensation for the roughness of the hole. Measurement from frame/crane level can however only be done after the gripper has been lifted from the hole.

Two possible approaches were studied, using a laser scanner or machine vision. Properties of both technologies were discussed in chapter Ensuring that block’s touch point is clean enough to ensure that the buffer and blocks are aligned vertically. Both technologies would reach the accuracy target needed in the gap width measurement. However the laser scanner has still the same disadvantage to its use in that the acquiring, data transfer and analysing takes several minutes.

Machine vision provides a fast method to resolve the dimensions in this particular case. The bentonite block installed into the hole was produced to very tight manufacturing tolerances and so can be used as measuring scale to resolve the gap width from the picture. This type of check is possible when the measurement of the gap between the rock and top surface of the block is desired. The cost of using machine vision is the same as presented in chapter Ensuring that block’s touch point is clean enough to ensure that the buffer and blocks are aligned vertically. Both tasks could share the same hardware (camera+ support electronics etc.)

2.3.3 Recommended Approach

Machine vision is the most promising method for gap measurement.

2.4 QA4: The compactness of the joint between the pellets and the host rock.

2.4.1 Background and Motivation

The surface geometry created when the gap between the host rock and bentonite block was filled with bentonite pellets needs to be measured to ensure that the minimum density of the bentonite buffer block/pellet system is reached. The pellet filling is planned prior to the actual buffer installation using a 3D model of the hole to be filled. This allows using premeasured amounts of pellets to be loaded into the compartments of the container so that the variation in the gap width (due to hole drilling tolerances) can be compensated. Pellets are released per each block after the block has been lowered to correct XY-coordinate but the block hasn’t been released yet (or the transport container hasn’t been moved from the release position).

The main concern associated with pellet discharge into the gap is that pellets may form bridges which cause empty spaces in the filling, which decreases the density achieved. In addition to a decrease in buffer density there is a risk that bulking resulting from bridging could mean that pellets may end up to the touch point surface. This would be an operational issue since they would need to be removed before further block installation could occur.

2.4.2 Studied Approaches

The target of measuring the material in the outer gap is to reach the accuracy level of approximately one pellet thickness in formation inspection. The fact that the top part of the container (which carries the block) is wider than a bentonite block is a complication in achieving this QA task.

There are two candidates to tackle the challenge of acquiring these measurements, laser scanning and machine vision. Both have been represented earlier in this document in respect of accuracy, measurement times, costs etc. The measurement distance is also the same as in chapter QA3: The width of the gap between assembled block and the host rock.

However, acquiring these measurements becomes harder block by block as the outer edge of a block shadows the gap the closer the block is to the sensor. In practise this means that the sensor should move above the gap so that there is always line of sight to the gap. The same mechanics that can be used in direct pitch and roll measurement of the assembled block with a laser distance meter as in chapter (Measuring the pitch and roll angles of assembled bentonite block to ensure that the buffer and blocks are aligned vertically) could be utilised also in this case to provide exact distance information.

Measuring the surface geometry of the existing gap fill with a gripper mounted sensor before releasing the block would have a blind sector present. The width of the blind sector would be approximately 8mm. Another difficulty in measuring with sensors which are mounted on gripper's pads is that only 20-30 % of the filling surface could be scanned with 3 sensors. The number and position of the sensors are defined by the support pads (3 pieces, spaced evenly (120 degrees between each)). Despite these limitations, the advantage of gripper mounted sensors is that the measurements could be done in prior releasing the block. This would allow for conduct of corrective actions (which are undefined) to address uneven pellet filling.

The alternative of measuring from the level of BIM's frame or crane means there won't be any blind sectors caused by the container. The drawback is that because the block has already been released it may be even harder to make any actions to correct the situation.

2.4.3 Recommended Approach

A laser scanner is good solution to measurement of 3D formations. The only disadvantage is that measuring, data transfer and analysing consumes several minutes. This might restrict the usage in applications which require response time of few minutes at maximum.

Because of the slowness of the laser scanning option, Machine vision (photogrammetry) is also recommended for use in accomplishing this QA task. While not an ideal solution for 3D mapping machine vision is deemed to be accurate enough and the same instrument could also be used to other QA tasks such as gap width measurement and the touch point cleanliness inspection.

2.5 Summary of the feasibility study

Based on the study all QA targets QA1-4 are feasible and the probability of successful implementation is high. As a result, the estimated sensor cost of the BIM was decreased by using less expensive sensor technologies and using the same sensor in more than one QA task. The probability of meeting the QA process development schedule has been increased by choosing technologies that will require only moderate engineering effort to adapt them to these repository applications.

3 DESIGN

This chapter consists of the specification of the QA approach that was chosen and analysis on why there are deviations from the recommendations presented in the chapter 2 feasibility studies.

Visual inspection with camera recording noted to be sufficient for conduct of a second crack detection procedure just before installing the buffer blocks.

3.1 QA1: Integrity of the Buffer Blocks during the installation Process

3.1.1 Chosen Approach

The same images captured by camera as part of final pre-installation block integrity inspection are used to check the positioning quality of buffer blocks. This way the execution is kept simple and the inspection time needed for of the blocks is shorter than those presented in the initial feasibility studies. This keeps the implementation as simple and cost-efficient as possible, which in turn affects the resources needed, planning time and keeping on schedule for the development phase.

3.2 QA2: The Position of the Bentonite Blocks and the assembled Buffer.

3.2.1 Measuring the pitch and roll angles of assembled bentonite blocks to ensure that the buffer and blocks are aligned vertically

A laser targeting system was chosen to be installed on BIM. A laser tracker is mounted on the frame of the machine and it targets the top of the container holding the buffer block in order to accomplish the vertical alignment inspection. The laser system can also be used in the positioning of the machine. This would facilitate minimizing the installation planning time for each borehole installation and keeping the installation schedule.

3.2.2 Approach to ensure that block’s touch point is clean enough to ensure that the buffer and blocks are aligned vertically

Visual inspection of images of the top surface of previously installed block via camera was chosen as the sufficient method to identify possible presence of foreign particles on the joint surfaces. Its primary advantage is its speed of completion relative to a machine vision based method. This method also ensures the simplicity and cost-efficiency of the implementation – in addition to the savings on planning time and maintaining the installation schedule.

3.2.3 Approach to ensure that the whole buffer and each block are placed within ±1 mm tolerance to the planned XY coordinate.

A laser tracker system with targets was chosen as the only viable option for XY-positioning quality requirements. The original plan for accomplishing this action consisted additionally of laser based distance sensors installed on the frame of BIM which would be used to verify the alignment of the buffer block and the top of the container. However, based on the problems encountered in the field tests, the laser measurement was replaced by manually operated external tachymeter. In addition to the tachymeter measuring device, 6 laser distance sensors are installed in 3 pairs on the support structures in the lower frame of BIM. Figures 3-1 to 3-3 show measurement of XY-position difference between block and container.

Fig 3-1: Right front lasers

Fig 3-2: Right rear lasers

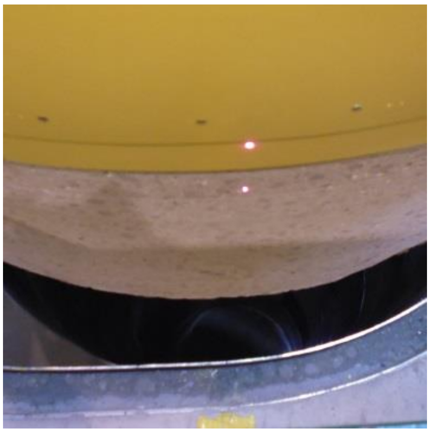

Fig 3-3: Left middle lasers

3.3 QA3: Determining the width of gap between assembled block and the host rock

3.3.1 Chosen Approach

Visual inspection of images via camera was chosen as the method for assessing the successful installation of the buffer block. It is a faster method than machine vision and laser based methods while ensuring the simplicity and cost-efficiency of the implementation. This method will also result in savings on planning time and assist in keeping the buffer installation schedule.

3.4 QA4: The compactness of the joint between the pellets and the host rock

3.4.1 Chosen Approach

Visual inspection based on the images of the camera was chosen as a sufficiently accurate method for successful pellet filling procedure. It is also faster to accomplish than the machine vision and laser scanning based methods introduced at the "Feasibility Studies"-chapter. Once again this approach has the advantage of minimizing the required planning resources and improves installation time efficiency.

4 TESTING

The field testing of the various means of measuring and assuring the accuracy of block placements were done in Eurajoki, in the ONKALO demonstration tunnel at the -420 meter level. The hardware used in these tests consisted of cameras by Axis and API Omnitrac 2 laser trackers and an external tachymeter that was not part of the final quality inspection assembly. The images of the camera feed were inspected on an operating computer that was connected to the system with a wireless connection. Quality inspection utilized the working lights that were installed on BIM. Light setup was as follows: 6 working lights on the loading area of the machine; 2 on the lifting area and 4 on the front part of the machine - on the frame structures. The working lights on the lifting carrier also served to light the area of the deposition hole.

The testing phases:

1. BIM's coarse positioning involves: backing the machine over the deposition hole, scaling of the frame and the gripper with the use of inclinometers.
2. Determining the coordinates and the position of BIM in relation to the tunnel coordination system. This is done by following and referencing the coordination markers on the tunnel with the laser tracker installed on the front frame of BIM. The positions of these markers in relation to the middle axis and the bottom of the test deposit hole are known.
3. Defining the position of the transport container top – attached to the mechanical gripper – in relation to the BIM's coordination system with a laser tracker.
4. Verifying the alignment of the buffer block and the container top in relation to the BIM's coordination system with a laser tracker.
5. Visual inspection to identify any defects on the buffer block.
6. Positioning of the buffer block in relation to the deposition hole.
7. Positioning of the buffer block and inspection of the blocks joint surface for particles and the space between the block and the deposition hole's walls.
8. Repeat the steps 3 to 6 until the installation of bentonite buffer is finished.
9. Verification of the bentonite pellet filling.

4.1 QA1: The integrity of the Buffer Blocks during the Process

The side and upper surfaces of the buffer blocks are inspected for possible cracks, color changes or other abnormalities with the use of camera images.

4.1.1 Task 1: Integrity of the side surface of the buffer block

Integrity of the side surface of the buffer block is verified with the use of camera feed after the block has been lifted with the gripper. The cameras are non-rotatable and installed on the loading area, 1 on both sides of the area. Figure 4-1 through Figure 4-4 show images of these cameras and what they would see during their use.

Fig. 4-1: Two non-rotatable cameras on the loading area

Fig 4-2: Left camera view

Fig 4-3: Right camera view

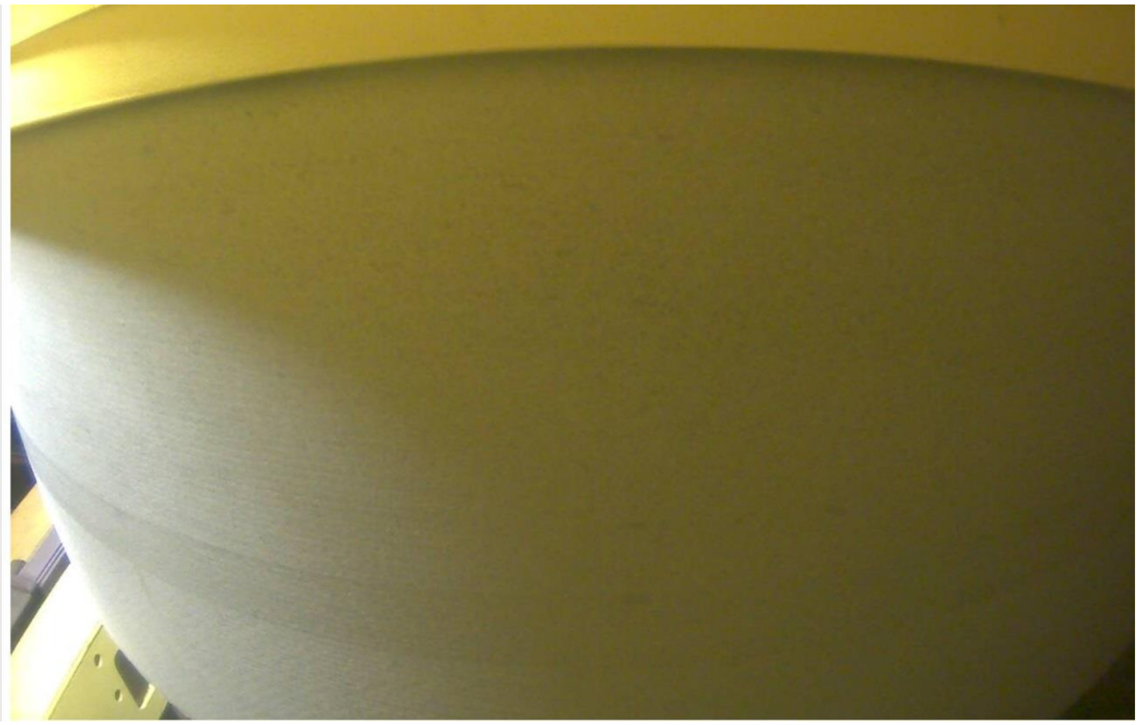

Fig 4-4: The inspection of the uplifted buffer block’s side surface

4.1.2 Task 2: Integrity of the upper surface of the buffer block

Integrity inspection of the buffer block's upper surface happens after the buffer block is lowered to the final deposit hole and the gripper has been lifted out of the deposition hole. The inspection is done with the use of a rotating camera installed to the lifting area of BIM (Figure 4-5). This camera has a built-in zoom capability to facilitate the inspection of buffer blocks on different levels (Figure 4-6 and Figure 4-7).

Fig 4-5: Rotatable camera installed on BIM

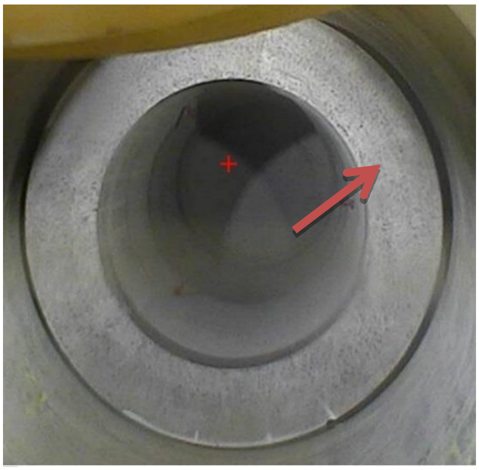

Fig 4-6: Upper surface inspection of the lowered buffer block (arrow)

Fig 4-7: Close-up inspection of the upper surface of the simulated buffer block

4.2 QA2: The Position of Assembled Buffer and the Bentonite Blocks the Buffer consists of.

The quality of the positioning of the assembled buffer and the bentonite blocks the buffer depends on the positioning of the buffer block and its adjustment during the installation phase. This adjustment process is based on the information gathered from the camera feed, laser tracker and tachymeter. Sections 4.2.1-4.2.6 outline the tasks involved in accomplishing block placement and quality checking.

4.2.1 Task 1: Position of the Container top

This involves defining the position of the container top attached to the mechanical gripper in relation to the BIM's coordination system with a laser tracker attached to the upper frame and markers on the container top.

4.2.2 Task 2: Alignment of the buffer block and container top

Alignment of the buffer block and container top is measured with an external tachymeter after the buffer block has been lifted from the container with the gripper. This will result capturing of position information of the buffer block and how it deviates from the container top position. This information helps in determination of the buffer block position in relation to the BIM's coordination system.

4.2.3 Task 3: XY-positioning and correction of the buffer block

The X-Y position of the buffer block with regards to the deposition hole's vertical axis is measured with a laser tracker installed on BIM's upper frame, after the block has been lowered into the deposition hole. X-Y correction is made based on the received locational information with the help of wall grabbing actuators installed on the gripper. Because the friction between the wall-grabbing actuators and the walls of the hole prevents the rotation of the gripper and could result in its jamming, this positioning task is repeated several times before final lowering into contact with the underlying block or surface occurs.

4.2.4 Task 4: Inclination of the buffer block

Inclination of the buffer block is inspected with the laser tracker – installed on the upper frame of BIM –when the buffer block is lowered to its final position in the deposition hole before releasing of the block occurs.

4.2.5 Task 5: Upper surface inspection of the buffer block

Surface inspection of the buffer block's upper surface for the presence of foreign particles happens after the buffer block is lowered to its final position in the deposition hole and the gripper has been lifted out of the hole. The inspection is done with the use of a rotating camera installed to the loading area of BIM which has an inbuilt zoom to facilitate the inspection of buffer blocks on different levels (Fig. 4-8 and 4-9).

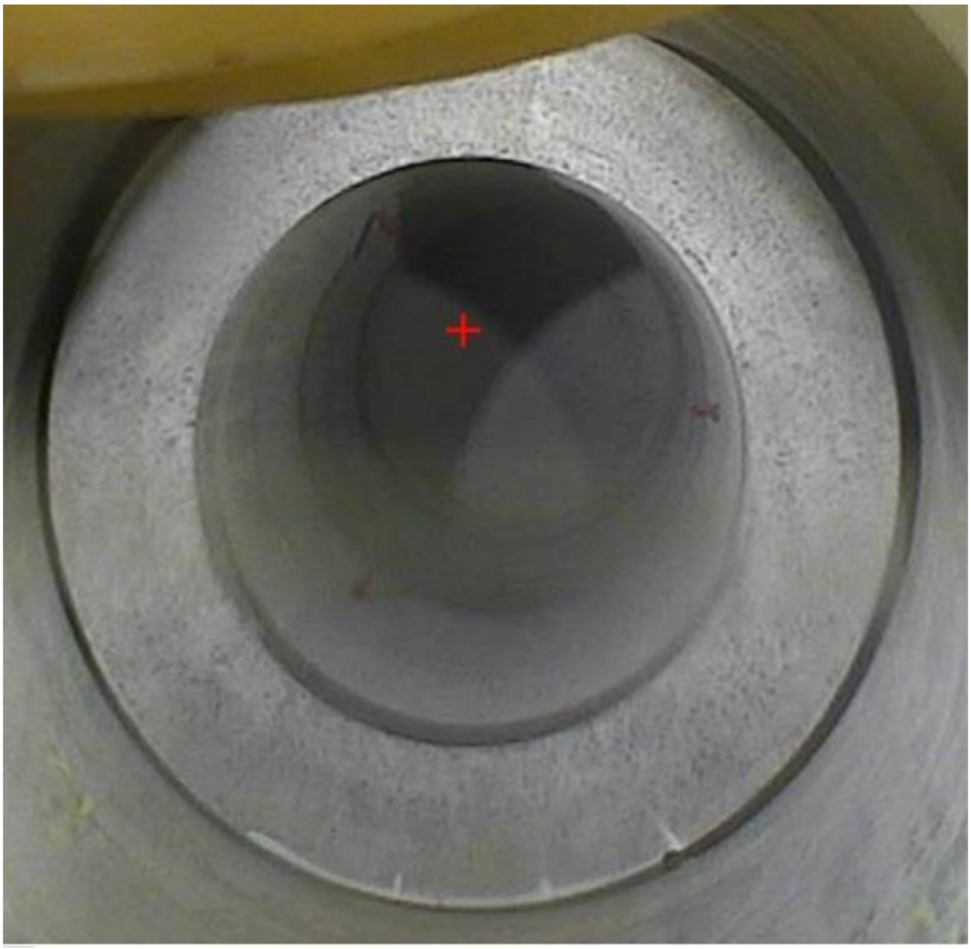

Fig 4-8: Inspection of the upper surface of the buffer block below series of installed ring segments.

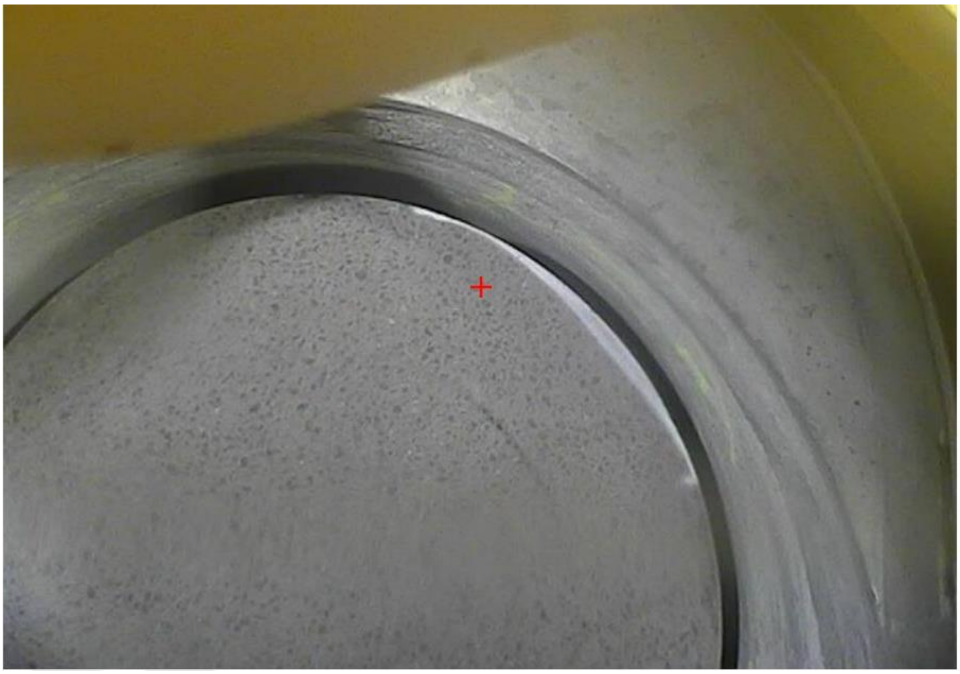

Fig 4-9: Inspection of the upper surface of the buffer block following gripper release.

4.2.6 Task 6: Inspecting the alignment of the assembled buffer blocks

Alignment of the buffer blocks to ensure that there is no misalignment between the assembled blocks is inspected at the inside surface of the ring buffer blocks. The inspection is done with the use of a rotating camera installed to the loading area of BIM which has an inbuilt zoom to facilitate the inspection of buffer blocks on different levels (Fig. 4-10).

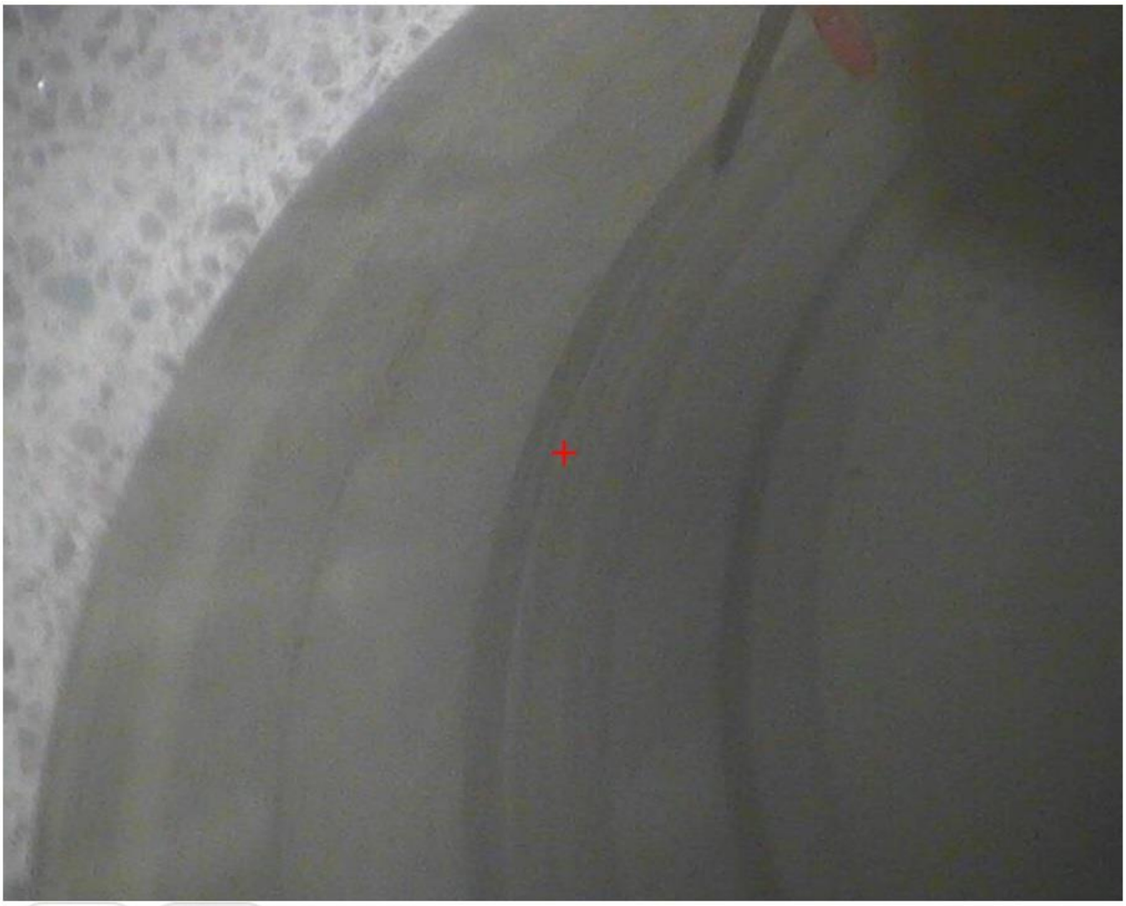

Fig. 4-10: Inspection of alignment of the assembled simulated buffer blocks with joint location (red cross symbol).

4.3 QA3: The width of the gap between assembled block and the host rock

Positioning of the buffer block within the deposition hole was previously completed as task 4.2.3, so the buffer block should already be on the right position. Taking this previous inspection into account, visual inspection of the width of the gap between the host rock and the assembled block is considered to be sufficient as a final check.

4.3.1 Task 1: Width of the gap between the host rock and the assembled block

Inspection of the width of the gap between the host rock and the assembled blocks happens after the buffer block is lowered to the deposition hole and the gripper has been lifted out of the hole. The inspection is done with the use of a rotating camera installed to the loading area of BIM which has an inbuilt zoom to facilitate the inspection of buffer blocks on different levels (Fig. 4-11 to 4-13).

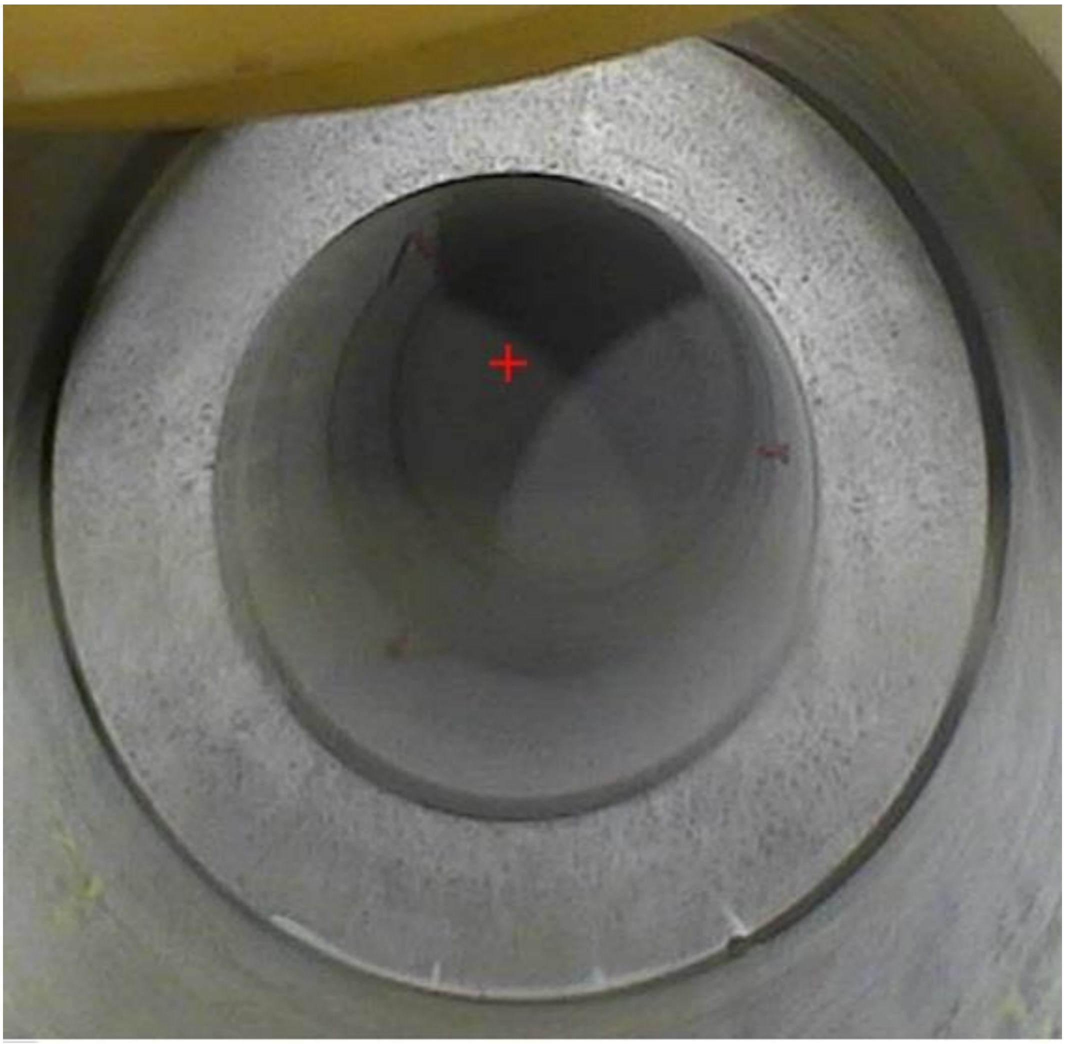

Fig. 4-11: Inspection of the gap between the host rock and the buffer block

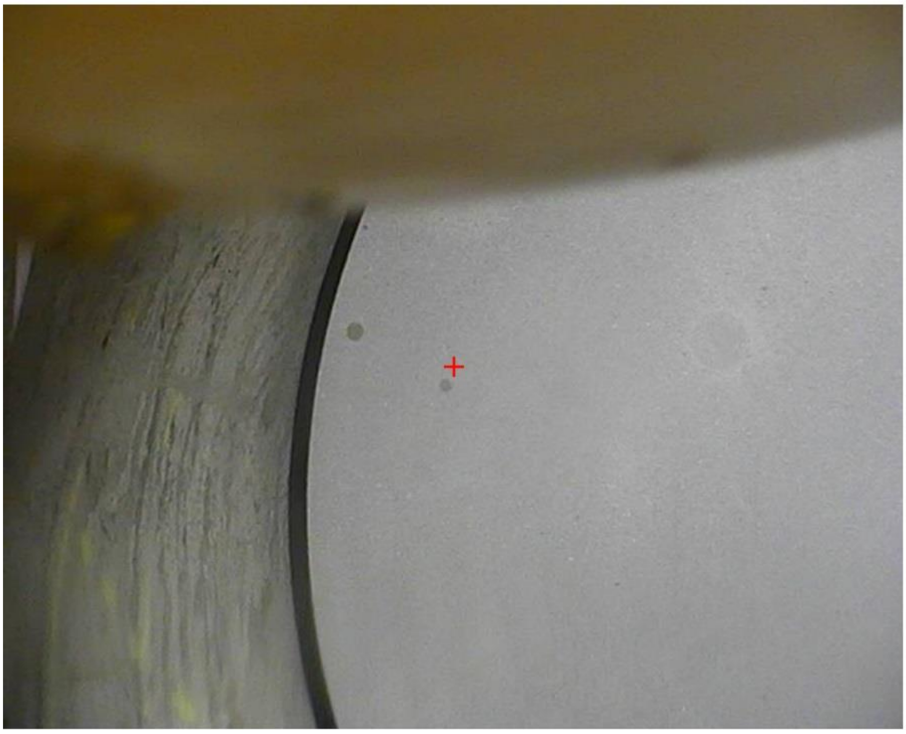

Fig. 4-12: Inspection of the gap between the host rock and the buffer block

Fig. 4-13: Inspection of the gap between the host rock (bottom) and the simulated buffer block (top)

4.4 QA4: Compactness of the joint between the pellets and the host rock

4.4.1 Task 1: Pellet filling

Visual inspection of filling the gap between host rock and the buffer block with pellets is done via camera feed. The dome camera on BIM lifter was used in the conduct of the placement testing. The pellets should be evenly distributed at appropriate level and must not end up to the upper surface of the buffer block.
This inspection is practically similar to QA2 Task 5 inspection; pellets are distributed evenly enough if there are no pellets on the block top surface

5 SUMMARY

The methods described on this report have been developed to assure that the bentonite buffer installation can be accomplished based on the quality and precision requirements set. Some deficits regarding monitoring still persist and the installation process still takes too long. The methods identified as being most suitable for use in inspection should be further developed and demonstrated as being viable, or new solutions developed to ensure the installation and quality assurance processes can be successfully accomplished.

5.1 QA1 Integrity of the Buffer Blocks during the Process

5.1.1 Task 1: Integrity of buffer block's side surface

Visual inspection of images via camera was the selected method for the integrity inspection of the buffer blocks. Currently, the camera angle achieved with the two cameras installed is roughly sufficient for inspecting half of the buffer block (Fig. 5-1 through Fig. 5-3). Re-positioning already installed cameras and adding additional cameras would result in the possibility of fully inspecting the side surface of the buffer block. The lights should be made adjustable for setting the light to an optimal level for each camera.

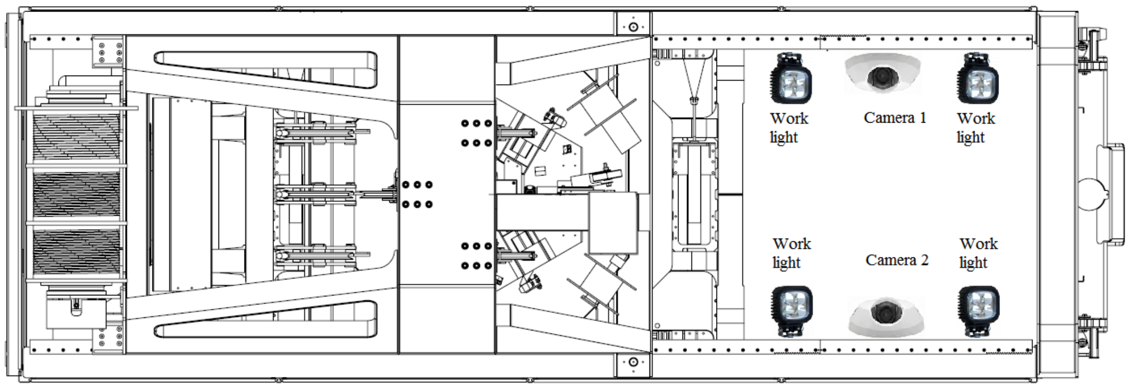

Fig. 5-1: Current setup of cameras and lights of the loading area of BIM.

Fig. 5-2: Current setup of cameras and lights on the right side of the loading area of BIM.

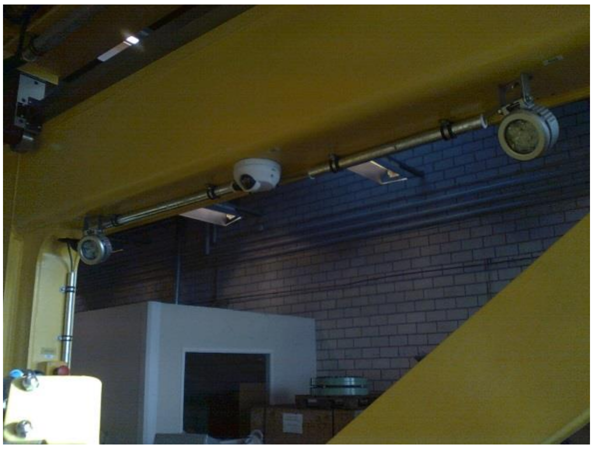

Fig. 5-3: Current setup of cameras and lights on the left side of the loading area of BIM.

5.1.2 Task 2: Integrity of buffer block’s upper surface

Visual inspection of images via camera is used to the positioning quality of buffer blocks. The current positioning of these cameras is shown in Fig. 5-4 and Fig. 5-5.
During the inspection of the buffer block’s upper surface the gripper occasionally obstructs the camera view – thus hindering the visual inspection quality. In that regard the installation of an additional camera(s) should be planned.

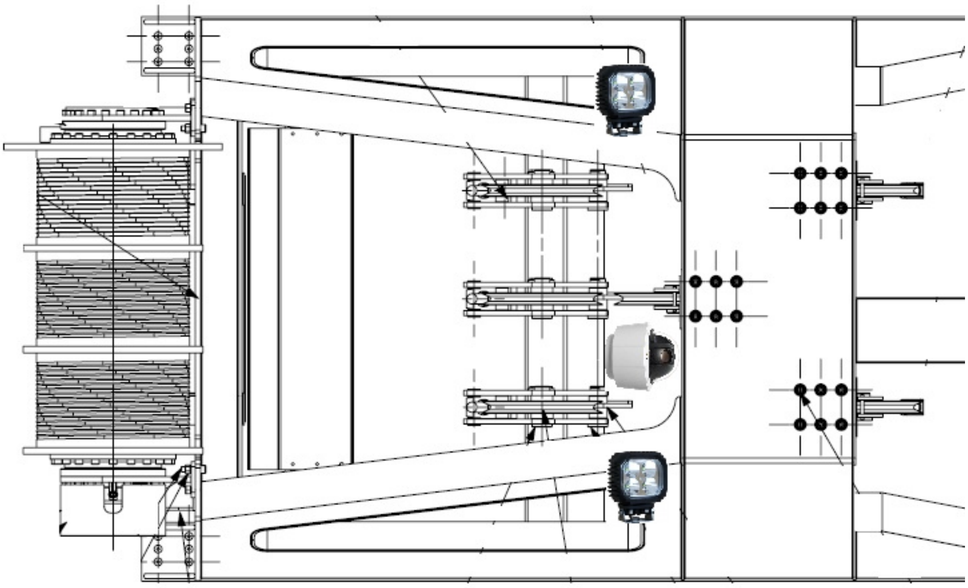

Fig. 5-4: Dome-type camera and lights of the lifting area.

Fig. 5.5: Dome-type camera of the lifting area.

5.2 QA2: Position of Bentonite Blocks and assembled Buffer

A laser targeting system was installed on BIM; the laser tracker on the frame of the machine and the targets on the container top holding the buffer block are used for the vertical alignment inspection. The laser system can also be used in the positioning of the machine.

Visual inspection of images via camera was chosen as the sufficient method for assessment of foreign particles on the joint surfaces.

5.2.1 Task 1: Position of the container top

While the precision requirements are met with the use of a laser tracker, the continuousness of the measuring routines should be developed further in order to allow for greater ease of positioning and allow for achieving the goal of completing buffer assembly within 2 hours.

5.2.2 Task 2: Alignment of the buffer block and container top

Alignment of the buffer block and the container top is currently done with an external tachymeter which is not appropriate in the final implementation. There are two requirements driving the need to abandon the use of tachymeter; the need to measure the buffer block position in the container as part of the container loading process and laser based distance sensors installed on the frame of BIM (Fig 3-1 to 3-3) should be commissioned.

5.2.3 Task 3: XY-position of the buffer block

Laser tracker system with targets is used for ensuring XY-positioning quality requirements.

Wall-grabbing actuators should be developed further to function better; currently the friction between the actuators and the host rock sometimes results in jamming the gripper. When the gripper is jammed it cannot rotate freely and the laser tracker must then be used multiple times to verify if the new position is correct.

XY-position measuring is successful when Tasks 1 and 2 are done thoroughly. The final inspection is done visually from the camera feed. The same development needs for the laser tracking of the block apply as were identified for Task 1.

5.2.4 Task 4: Inclination of the buffer block

Inclination inspection requirements are met using the laser tracker. The actual measuring is done in Task 1, so the development needs are the same as in Task 1.

5.2.5 Task 5: Upper surface inspection of the buffer block

The final upper surface inspection is done visually using the camera feed. During the inspection of the buffer block's upper surface the gripper occasionally obstructs the camera view – thus hindering the visual inspection quality. In that regard the installation of an additional camera(s) should be planned.

5.2.6 Task 6: Alignment of the assembled buffer blocks

The final buffer block alignment inspection is done visually from the camera feed. During the inspection of the buffer block alignment the gripper occasionally obstructs the camera view hindering the visual inspection quality. In that regard the installation of an additional camera(s) should be planned.

5.3 QA3: The width of the Gap between Assembled Block and the Host Rock

5.3.1 Task 1: Width of the gap between the host rock and the assembled block

The width of the gap between assembled block and host rock is inspected visually from views provided by the BIM dome camera. During the inspection of the gap, the gripper occasionally obstructs the camera view hindering the visual inspection quality. In that regard the installation of an additional camera(s) should be planned.

5.4 QA4: Compactness of the Joint between the Pellets and the Host Rock

5.4.1 Task 1: Pellet filling

The compactness of the joint between pellets and host rock is inspected visually from views of BIM dome camera. During the inspection of the pellet filling the gripper occasionally obstructs the camera view hindering the visual inspection quality. In that regard the installation of an additional camera(s) should be planned.

6 Summary

Methods to ensure the overall quality of the bentonite buffer that surrounds the spent fuel canister, in the vertical deposition hole of a KBS-3V-type emplacement geometry have been developed and tested. The main aim of the work described in this document was to define quality requirements for buffer emplacement work and gap filling, as well as designing and testing the quality assurance equipment and control procedures. There is still work needed to address some challenges regarding completeness of field measurement techniques and also the rate at which placement can be accomplished but the basic operations of the installation approach have been demonstrated as being viable.

7 Acknowledgement

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