Getting A Good Push: Improving the Baader 212's Head Pusher for Increased Recovery and Quality

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Abstract

The American fish processing industry occupies a small, niche part of the industrial world but offers substantial areas for improvements. Mechanical fish processing efficiency is one of these areas. The current version of the Baader 212 fish processing machine does not adept well to size, shape, and mass variation, so it was altered. This thesis aims to explain the process of enhancing Baader's factory head pusher for increased recovery while increasing quality and machine consistency in the fillet cuts.

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Introduction

Television shows like *Deadliest Catch* and *Dirty Jobs* already romanticize the beginning of fishing through their representation of the job, but few if any forms of media show processing of fish from the machinery/technician's perspective. Commercial maritime seafood processing is the dirty and fast process not only of pulling fish from the ocean, but also beheading and degutting them, reforming the product into the desired form, then flash freezing them for shipment. The entire process takes place on a fishing vessel, and then the product is offloaded into a major port where the frozen blocks are dispersed throughout the country for consumers or repurposed again at another manufacturing plant. In America, the fishing industry that supplies the highest percentage of fish is the Alaskan Pollock industry. A few companies and boats provide 39% of US fish value each year and catch roughly 1.6 billion tons of product (Fisheries, 2020). The Bearing Sea fish processing industry supplies all the United States' Alaskan pollock. Despite making up these impressive numbers, the industry is comprised of only 23 boats and a few shore plants, which are not active simultaneously, and just a handful of companies staffing them (NOAA Fisheries, 2020). These boats operate in a highly efficient and fast process to keep up with American demands. This thesis aims to briefly describe and analyze the manufacturing process, emphasizing the efficacy of improvement by altering the Baader 212's head and gut section. The focus of the process will be on the fillet machinery.

Processing

The major companies fishing for pollock focus on the most popular and profitable product: the fillet. Fillets are the most common fish product on the store shelf and are internationally used to create other products such as fish sticks, seafood salads, and kamaboko in Japan. Pollock's versatile nature in so many dishes requires machines that can optimally behead, gut, and scissor the fish open for easy freezing and storage while still saving some rejected pieces and roe to be used in other products. The machines that squeeze the roe, behead, and fillet the fish are the key points in every boat's operation, and without their speed, the industry could not function today with so few ships. The processing machine most used among the companies with the highest quota – American Seafoods, Trident Seafoods, Glacier Fish, etc. – is the Baader 212 ("Fish processing …", 2020). The 212 is used for its fast speed of 150 fish per minute because the entire process is condensed into one machine (Baader, 2021). The Baader 212 is capable of beheading, gutting, filleting, and roe recovery in one swift process. This speed and the financial saving of not requiring manual labor to tend to the fish make it a top pick in the companies with the highest quota and is the heart of the fish processing operation in nearly every boat.

Baader 212. The 212 requires that its process starts with workers, as each fish must be manually loaded into the machine. The process beginning with people is one of the few shortcomings, as the process is still not fully autonomous. Typically, the fish are loaded by one or two people called Drivers, then spun around by hand and fed onto the plastic tray conveyor. At this point, the machine takes over the entire process until they are egressed out as fillets ready for the freezing process. The first step of the processing machine is the removal of the head. Each fish is decapitated – in theory – at the optimal position thanks to the drivers straightening them as they come onto the conveyor system and the head pusher inside the machine. As the fish heads are sliced, they drop – in most cases – to a lower conveyer that sends the heads to another location in the factory for further processing or, in some cases, a Scalper/Chinner combination that cuts off more meat (Figure 2). The headless product then slides not even a foot further before a mechanism on the 212 squeezes the guts and roe from the belly. Both the roe and major organs of each fish hit another conveyer belt and become repurposed as roe on its own through a minor recovery process that separates the eggs from the organs. At the same time, the waste from the process is sent to be ground up and reused in another recovery process (Chapman, 2018). The fillets then transition farther down any of the byproducts that are still hanging on to the fish's carcass are rolled off with a brush. At this point in the process, the fish are still whole but missing their head and guts.

A Baader 212 starts with the fish vertically loaded (from the driver's perspective), but after the initial degutting and beheading, the fish "drops" to a lower level. The fish's position doesn't change, but how the fish is fed through the machine has switched. The initial section positioned the fish vertically from the driver's perspective, but due to the machine being set at a 90-degree angle, they transitioned horizontally ("Device …", 1996). This final stretch of the machine is where the filleting process takes place as each final cut is made to shape the fish into the desired product. Directly before the head pusher contacts the fish, a roller is positioned and attached to an angle encoder. This encoder estimates the mass and location of each fish in the machine to be later used for the pin bone cut and the flank cut. Each fish is measured using rollers and aligned with Polyurethane and Stainless-Steel wedges to slightly alter the blades for each fish coming down the assembly without jarring the fish too much. The measurements taken are where part of the 150 fish per minute comes from; each fish that drops needs to be measured to ensure all the meat is recovered. The Baader machines, and these blades, can compensate for fish measuring 37-55cm (about 1.8 ft) and a mass of no more than 1500 grams (Baader, 2021). The skates and wedges that align the fish for each fillet slice and pin bone slices can't compensate for anything larger than this without throwing away product or, in some cases, throwing the machine out of alignment if the pollock is too tall to fit the guides (Figure 3). This short alignment is the key to all the cuts. If alignment is off even a fraction of a millimeter from how the centering rollers straighten the fish, pin bones could remain in the fish, the belly cut could be at the wrong angle, or the fillet's quality could be ruined in a severe case. The alignment of the 212 is a core focus of the technician working on these machines, as this is where recovery is gained. The entire fillet operation relies on how the roller and alignment wedges are positioned. Going faster/bigger and cutting corners can throw away small fractions of meat that add up to tons of product; this leads to the cutting process after the heading section and initial measurements.

The 212's fillet section has six cuts (Belly, Flank, Bone, Trunk, Pin bone, Severing), but the three significant cuts – the belly cut, the flank cut, and the pin bone cut – will be the focus for describing the fillet process ("Apparatus …", 1988) (Figure 1). The first cut begins directly after the fish goes through the centering rollers and after it drops from the horizontal section to the vertical section of the machine. This cut splits the fish down the middle without cutting all the way through. The fish is essentially "butterfly" cut and then laid flat as the guides continue to straighten the product and spread the pollock out to be flat. Spreading the pollock allows the flank cut to be precise at salvaging meat ("Device …", 1996). The cut consists of two rotary blades positioned at a high angle toward each other, powered by a step motor to move the cut position while chain-drive AC motors driving the blades shred off the rib section of the fish. The angle allows for the knives to follow the contours of the fish, leaving an optimal amount of product ("Apparatus …", 1988). This piece of boney meat still has product to be recovered and is another byproduct of the process like the head and guts. The flank cut pieces fall below to a catch that moves the product to another location in the factory, like roe. Removal of this layer leaves the fillets bare minus the rib section, where the pin bones are finally removed.

The pin bone arm's timing is where the initial measurement at the angle encoder means the most. As the pin bone blades move to cut the forwardmost meat, the timing and dwell of the arm's movement are determined by the prior mass estimates at the encoder (Baader, 2021). The pin bone cut is just as precise as the flank due to being controlled by a step motor as well. The arm of the pin bone blades moves up based on the timing of the fish and the machine speed calculated by the computer. After the pin bone blades take off the final bone portion, the only thing remaining is splitting the fish in half through the severing cut. This cut finishes the process and shoots out two perfect, bone-free fillets (one from each half of the fish after the severing cut is complete). After the fillet process is complete, only shipment and further processing remain if desired. The skinning process sometimes implemented in factories shreds off the outer skin, then packaging for shipment in cardboard boxes is done by hand and freezing for storage occurs. For the scope of the head pusher, only an understanding of the heading and fillet process is necessary.

The Head Pusher. The original design Baader developed for the head pusher is the one included standard on new machines today; however, there are other options available both from Baader and another manufacturer of parts. The first is Baader's official upgrade, the HA – short for Heading Attachment (Heading for..., 2022). This option is the official upgrade that is costly to both the technician and the company. The HA uses a rotating wheel that is expensive to maintain due to part consumption and is time-consuming for the technician to rebuild during an offload in port (Figure 4). Baader doesn't supply the technician with estimated times to rebuild, the equipment costs, or disassembly and reassembly instructions, so analyzing based on these factors, although a much stronger argument, is challenging to give a concise and definitive comparison. The same can be said for the DK (Dieter Ketel) heading attachment. The DK is the alternative to the HA and is produced by an ex-Baader engineer. This option sees a reduction in parts, repair time, and overall initial cost compared to the HA, but does not recover as much product as the HA, though it still recovers more than the factory attachment. Both are fantastic options, but understanding why modification of the original was necessary boils down to the initial cost for the company

Design Modifications

Both the HA and DK are great devices. Still, due to a few shortcomings – and financial constraints of the employer – the original design was updated by the author for the interim period of early May 2021 through late November 2021. The original head pusher was modified/updated with a spring-loaded shaft, a new Delrin bushing machined to fit the original pusher's design, and a Stainless-steel L-bracket arm slotted for weight reduction. The original pusher had a few modifications done by prior technicians that aided with recovery and were still a boon to the update, so they were left alone to be consistent in testing and reliability.

Arm. The update began with the arm, part #1, that connects the pusher assembly to the rear of the machine through part #19, the joint head (Figure 5). The upgrade for the arm was for both strength and stroke, as the increased length of the aft section allowed the joint head to move in a larger radius (Figure 6). The more significant stroke combined with a change from a 1-inch box tube to L-bracket allowed for high speeds without drastic weight changes (Figures 7 and 8). Due to fatigue failure during operation and inconsistencies, the arm itself went through a few variations. The first implementation and testing of the updated pusher, the factory arm, was used. The first variation was successful during the first 24-hours of operation. Still, around hour 30, the box tube was flexing to such a high degree that the step motor that runs the arms' "push and pull" motion was beginning to lose zero on the motor's position sensor. At first, this was not evident and assumed to be the pusher dragging across the head trays (Figure 9). An adjustment on the pushers' slotted bolts alleviated some of this, but after analyzing slowmotion footage of the operation, the Baader manager suggested weld reinforcements to the box tube arm. This method was also short-lived. No pictures or documentation were made due to this alteration only lasting a few hours before the added weight from the reinforcements broke the welds at the joint head end of the arm. The final iteration was built ground up and worked flawlessly through its roughly seven months of non-stop use, never losing zero or flexing like Baader's original and the reinforced original (Figure 8).

This new arm incorporated the same length of Baader's arm, but with 10mm (about 0.39 in) added to the joint head side of where the arm connects to the machine's backing for the increase in stroke. The same 45-degree angle in reference to the support was also used as there was no reason to alter with the machine's geometry of operation at the joint head, when from that aspect, the head pusher works flawlessly. The decision to use an L-bracket instead of a box tube like the original came down to weight, what was available onboard the vessel material-wise, and ensuring it wouldn't conflict with the arms operation. Going with a larger – or thicker – box tube posed a risk that was not worth taking when a 2mm (about 0.08 in) thick L-bracket with holes drilled for weight reduction would do the job fine without throwing the step motor out, nor breaking a weld. To simplify the arm's design philosophy: it was thicker, stronger, and only slightly heavier than the original without compromising the step motor. This improved arm was the last step in the process but was necessary to explain first due to its relation to the actual pusher (Figure 11).

Spring-Loaded Shaft. The shaft is where the basic design philosophy of the update comes into play: how can the pusher be kept from smashing the fish and ruining initial cuts? To understand the inclusion of the shaft with a spring, the head pusher's operation must be examined. As the fish are loaded by the driver and straightened, the head pusher moves forward, shoving the fish into the fin catchers, which “hold” the fish at the optimal location for the cut (Figure 12). The problem with the 212 lies in the adjustment of dial number 1 on the 212’s adjustment panel. The panel allows for mild tuning of the head pusher movement, the flank cut’s position, roe squeezer engagement, etc. Each dial can accommodate extreme fish variation— such as an entire bag of 400g fish to 800g fish size change – but isn’t perfect. Being able to change spring constants to accommodate small variations is where the spring-loaded shaft comes into play. We no longer are compressing the fish, but now we are allowing the shaft to “give.”

To explain the problems, the head pusher’s action will be examined from a physics aspect: when the head pusher engages, the fish slides across the tray’s surface, optimally lining up the fish for the head knife as the fin catchers “hook” the fins. The problem with this lies in the adjustment dial on the 212 itself. Optimally, the fish stops at the fin catchers and goes no further, but the geometry of each fish head changes too much. The typical solution is to change the dial setting to increase or decrease the stroke of the head pusher, but unless the issue is drastic, like a difference in fish quality between bags, adjusting the dial on a by-fish basis is impossible. From a physics perspective, when the fish collides with the head pusher, they become one mass, and the arm can keep pushing this increased mass into the fin catchers. They will hold the fish and keep it from progressing past the optimal range, but this is only if the arm stops. In every case, it is better to turn up the dial, increasing the stroke and “smashing” the fish into the catchers, than it is to have too short of a stroke and ruin the cut. A harder push turns our physics problem of the fish-head pusher mass into an immovable object, the machine. Something must “give” when the mass of the fish sliding with the head pusher contacts the fin catchers, and as the machine isn’t going to succumb to the low force of the arm, the fish head itself begins to crinkle (Figure 13). The spring-loaded shaft now mitigates the issue of the fish compressing and instead compresses the attached spring (Figure 14). This addition allows the same dial adjustment on the machine to “push” the fish harder and further into the fin catchers without distorting the product. To simplify the spring-loaded shaft reasoning, we can pretend the fish is a spring. We want the “fish spring” to have a lower spring constant than the shaft, so we can compress the shaft’s spring, not our fish, which would destroy our head cut’s accuracy and disrupt our fillet process.

Delrin Bushing. The original head pusher design incorporated two bearings where the shaft was installed (Figure 5, #23), so a new part would need to be designed to join both the shaft and the original head pusher. This part is a Delrin bushing that the 8mm shaft would sit inside and is press-fit inside the original housing (Figure 15). There is not much innovation in the creation of this part as it simply joins the existing and the new component. The outside diameter matches that of part number 31 in Figure 5’s illustration, and a slight bevel of half a millimeter was added for ease of pressing into the housing. The shank length of the bushing was chosen to be 42mm to mitigate wobbling of the shaft. Should this part be produced professionally with cost in mind, a shorter length should be used. Once the bushing and original housing were joined, no problems persisted with this component of the head pusher.

Testing Methodology

Every modification completed was based on observed reaction and theory of how the 212 reacts to inconsistency. The head cut is the first point of contact the machine has with pollock, and problems here can be noticed at the end of the machine where the pin bone cuts and severing cuts occur. How the fish reacts to machine change can be observed by how the fillet comes out of the machine and the final mass. The head pusher can change the angle of how the fish is cut and the amount of product being thrown away. The product being thrown away is measured using a recovery test; the test is quite simple, involving a percentage difference in mass before and after going through a machine section. To explain it in the simplest way possible: what goes into the machine is weighed and weighed again on the other side to see how much product has been lost. Since the head pusher is the first point of contact, there are no other variables such as flank adjustment, bridge settings, the head-to-fillet section transition, etc. that can cause the loss. Therefore, the only element being examined is the pusher and how the knife next to the pusher cuts.

Recovery Test. The recovery test to check the validity of the machine's upgrades was performed using the same methodology quality control managers use to assess the product. The only variation of the trial was removing the carcass before it became a fillet instead of doing an overall assessment of the machine, which would still show change, but with more variables than needed to assess the upgrades performed. During average production, the machines are checked daily with a recovery test to see how much product is being thrown away. This test gives the company daily numbers to compare the product while also indicating any significant fluctuations in machine performance that would affect operational output.

The process of the recovery test began with weighing each fish. The mass assessment was done in five tests of five fish from the same bag. Totals and results were added together to make up the entire 25-fish sample. The small Marel 1100 scale only necessitated groupings of five due to its size (Figure 18). The fish were pulled from the backline of production and were chosen to be the same approximate weight and size for consistency of the experiment data (Figure 17). After the scale was zeroed, the initial masses were documented, and when the factory was on break, testing of the pusher for each session began. Each fish ran through the pusher and head knife, but was removed before the roe squeezing process (Figure 16). The carcasses were then degutted by hand and placed back with their group for weight evaluation while this was repeated for each fish (Figure 19-21). This process of weighing five fish, running them through the machine, and repeating for 25 fish, was conducted three times for each machine over the span of a week. Three tests were done for each setup of the original factory head pusher and the updated spring-loaded design. Table 1 shows the results of the original arm, while Table 2 shows the results for the updated design.

Results

The updated head pusher performed superiorly to the original design, as anticipated. When analyzing quantitatively based on the mass percentage, the updated design left 50.94 percent meat while the original's average was 48.87. That is roughly a two-percent difference in the performance of the updated design based on a sample recovery test. Two percent is expected of such a minor change, but due to our fish spring no longer being overly compressed, the recovered meat percent is higher on the upgrade. The higher percentages do not account for the improved efficiency of the machine, only product output. To better understand how this improvement was qualitative, "The Drop" will need to be explained.

The Drop. The Drop is a location on the 212 where the fish transitions from the heading section to the fillet section. As the fish move along the tray drive system, the conveyer "rolls" the fish over an edge where they fall one foot before landing on the segment chain. The drop onto this segment chain is where the fish straddles the rotating humps that push the carcass to the fillet portion and where the spike chains pick up the fish (Figure 22). The head cut is relevant to this machine area because of how much belly cavity is left behind if the push is too shallow. When explaining the fish spring that compresses under excess force, we could have also mitigated this by backing off the head pusher's stroke. The problem with backing off this stroke is the gap created between the fin catchers and the fins. When we push less, the fish never gets seated in the fin catchers but when we push too much, the fish's head compresses (Figure 12). Backing off the push effectively yields more fish in the freezer if we look at this from a product kept versus product thrown out standpoint, but doesn't explain the method comprehensively.

We are cutting off more good meat to compensate for the arm's inconsistent push, leading to more meat removed alongside the head. In theory, the shallow cut results in a consistent fish position, yielding less product being thrown away. This doesn't account for the new problems created; a few examples created from this "fix" include head bone in the product, miscuts in the fillet section's six major cuts, and poor spike chain pickup performance creating other problems outside the scope of the 212. All these issues stem from the shallow cut including less belly due to more "good" meat being removed. As we allow the fish head to be cut farther from the knife, the amount of meat lost at the head cut increases. This increase in head length decreases the amount of belly able to straddle the segment chain as we lose the belly cavity volume when the knife moves closer to the tail area of the fish (Figure 20). The hollow space from where the guts reside is the key to the fillet section's operation. If this belly section is too small, it creates various inconsistencies that are not all the time, but frequent enough to affect the operation of the machine and cause the fish to "swim" around the machine (Figure 3).

The drop leads to the real benefit of modifying the head pusher: overall fillet quality. When the product can transition through the machine with a good foundation from the first cut, the rest of the machine follows through when adjusted correctly. This factor is exceedingly difficult to quantify as it doesn't show well in recovery numbers, product box, or length of trips fishing when measured by time. This is due to the "no waste" practice in the fishing industry. Every part of the fish from the guts, head, or bones gets used as another form of product. Fillet is only part of the fish processing industry and is the scope and focus of the head pusher, but it does affect how much waste enters other byproducts, such as surimi. When the fillets come out “cleaner,” the product is better, and fewer small bits end up in different locations for the byproduct. The small amount of mass kept from the recovery test is the closest we can come to showing the quality of the product, with mass being a determinant, but this doesn’t factor in how the rest of the machine reacts to this consistency. The fillets come out more consistent with their look, leading to more contracts with companies like McDonald’s, Gordon’s Fish Sticks, etc. This observation of the product quality is quantitative. Still, it is the most significant factor from the technician’s perspective to work with, as this is where improvements like the head pusher upgrade are derived.

Closing Remarks

Improving the Baader 212's Head Pusher improvement was a tedious process, but yielded a more consistent fillet while slightly improving the amount of product retained. The arm, spring-loaded shaft, and homemade bushing to tie everything together ended up being a significant boon to the machine's performance and recovery despite having a few initial issues. After testing and proof of concept, duplicate parts were produced for the remaining machines in the factory, resulting in the conversions being performed. The ever-changing product of fish from day-to-day, season-to-season, or year-to-year is the challenge of developing for this industry. Technicians do not know what they are dealing with until the product enters the machine, and unlike farm-raised fish, these fish aren't perfect, plump fish. Dealing with the daily inconsistencies in the product is what separates a fish-processing technician from technicians in other trades; it takes a true artisan to understand his machine and be able to modify it, and not just follow a step-by-step guide.

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Tables

Table 1

Fish Recovery of Original Head Pusher

Test Number	Quantity of Fish Tested	Before Mass (Kg)	After Mass (Kg)	Change in mass (%)
1	25	22.09	10.73	48.59
2	25	21.41	10.51	49.07
3	25	21.35	10.45	48.95

Table 2

Fish Recovery of Updated Head Pusher

Test Number	Quantity of Fish Tested	Before Mass (Kg)	After Mass (Kg)	Change in Mass (%)
1	25	21.75	11.14	51.21
2	25	21.47	10.88	50.68
3	25	21.55	10.98	50.93

Figures

Figure 1.

From left to right: Belly Cut, Flank Cut, Bone Cut, Trunk Cut, Pin Bone Cut, Severing Cut.

Figure 2.

The tank where heads are eventually relocated for further processing after the head cut's initial removal.

Figure 3.

A variety of issues can cause the fish to be thrown out of the spike chain drive. The machine was stopped then the fish was removed in this case as it was affecting function.

Figure 4.

Side view of the updated head section featuring the HA, pictured on the left side. (Baader, 2021)

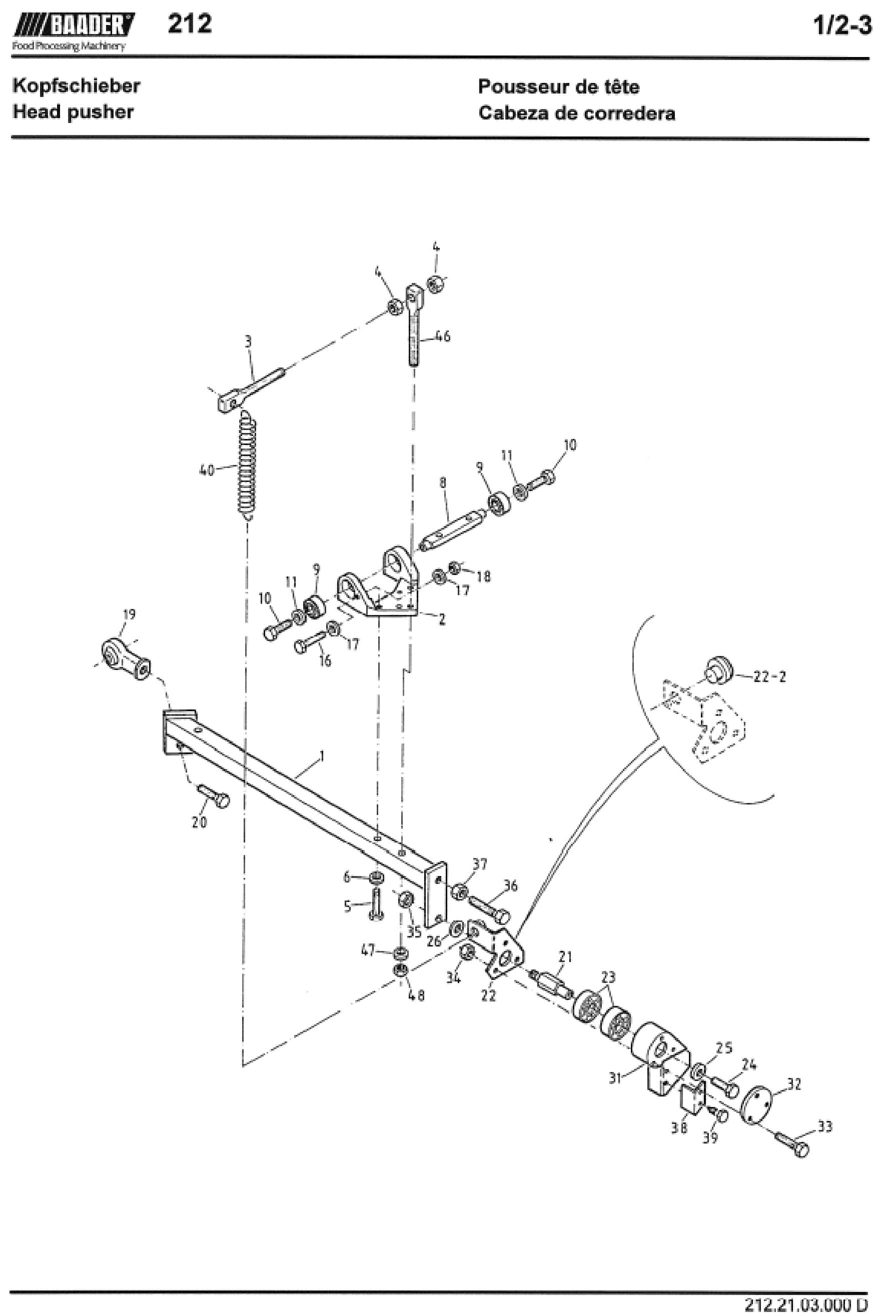

Figure 5.

The primary assembly of the Head Pusher from the 212's part book (Baader, 2000)

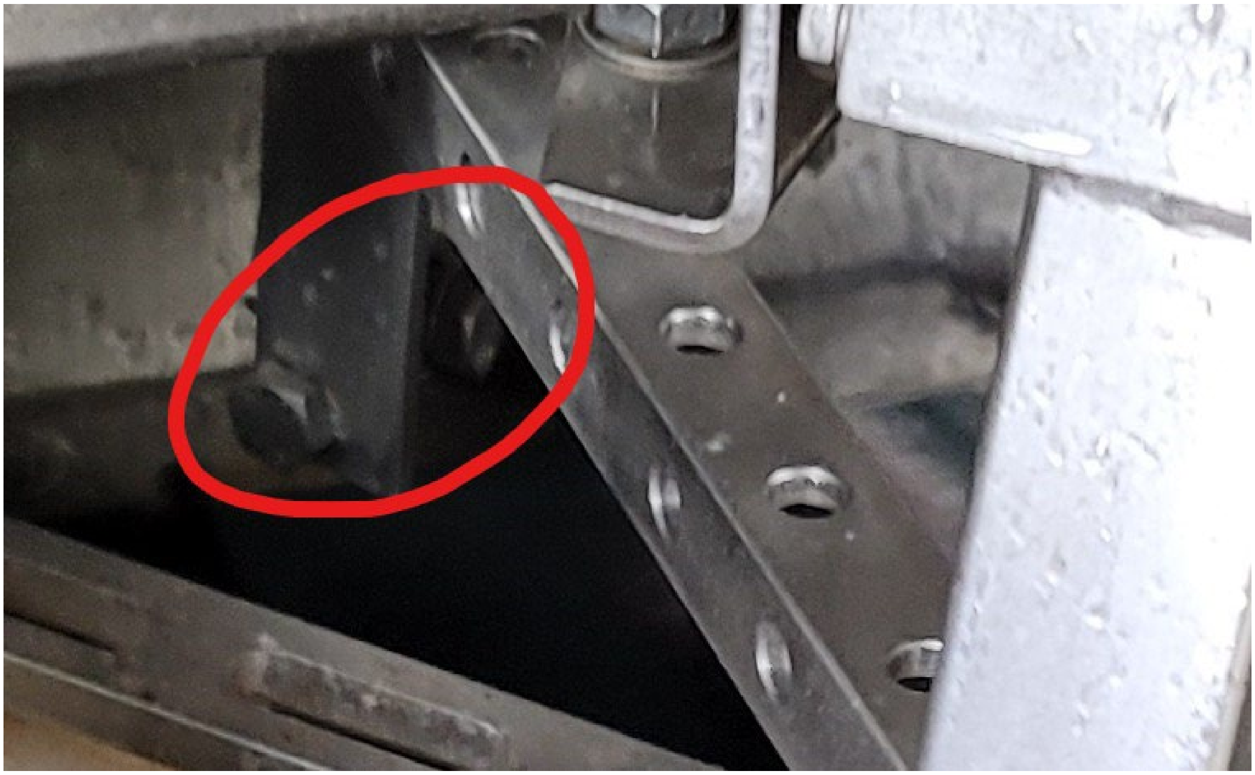

Figure 6.

Circled is the increased length for where the joint head connects to the arm, 10mm (about 0.39 in) total added in vertical distance compared to Figure 5.

Figure 7.

The increased stroke can be seen on the back portion of the arm and the change to L-bracket with holes drilled for weight reduction.

Figure 8.

Isometric view of the arm in Autodesk Inventor.

Figure 9.

The circled location was originally scrapping the bottom of the tray very softly due to the increased arms stroke.

Figure 10.

The before photo of the arms creation, minutes later, I welded them together and drilled the holes for weight reduction and mounting.

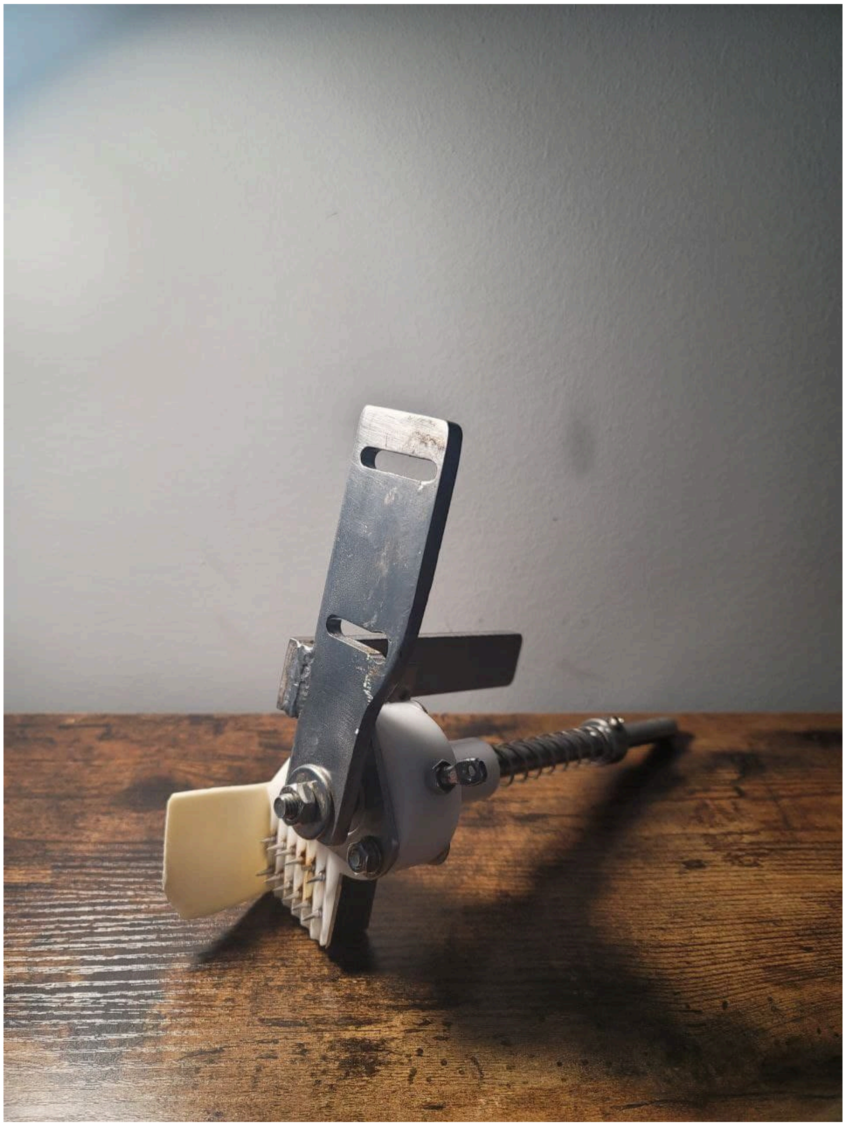

Figure 11.

The assembly of the head pusher. The slotted holes on the front are where the pusher assembly connects to the arm.

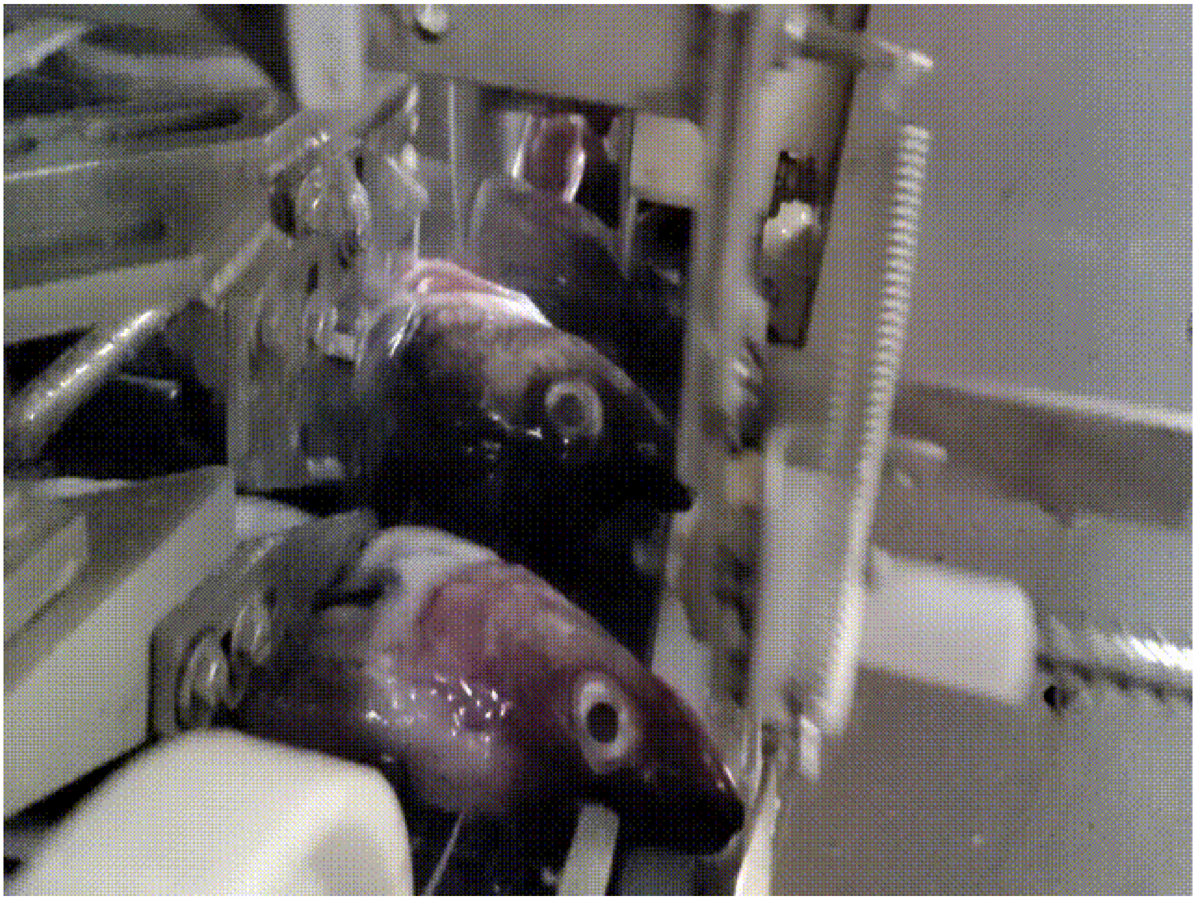

Figure 12.

The fin catchers “catching” the fish as they move to the head knife after the head pusher’s deployment.

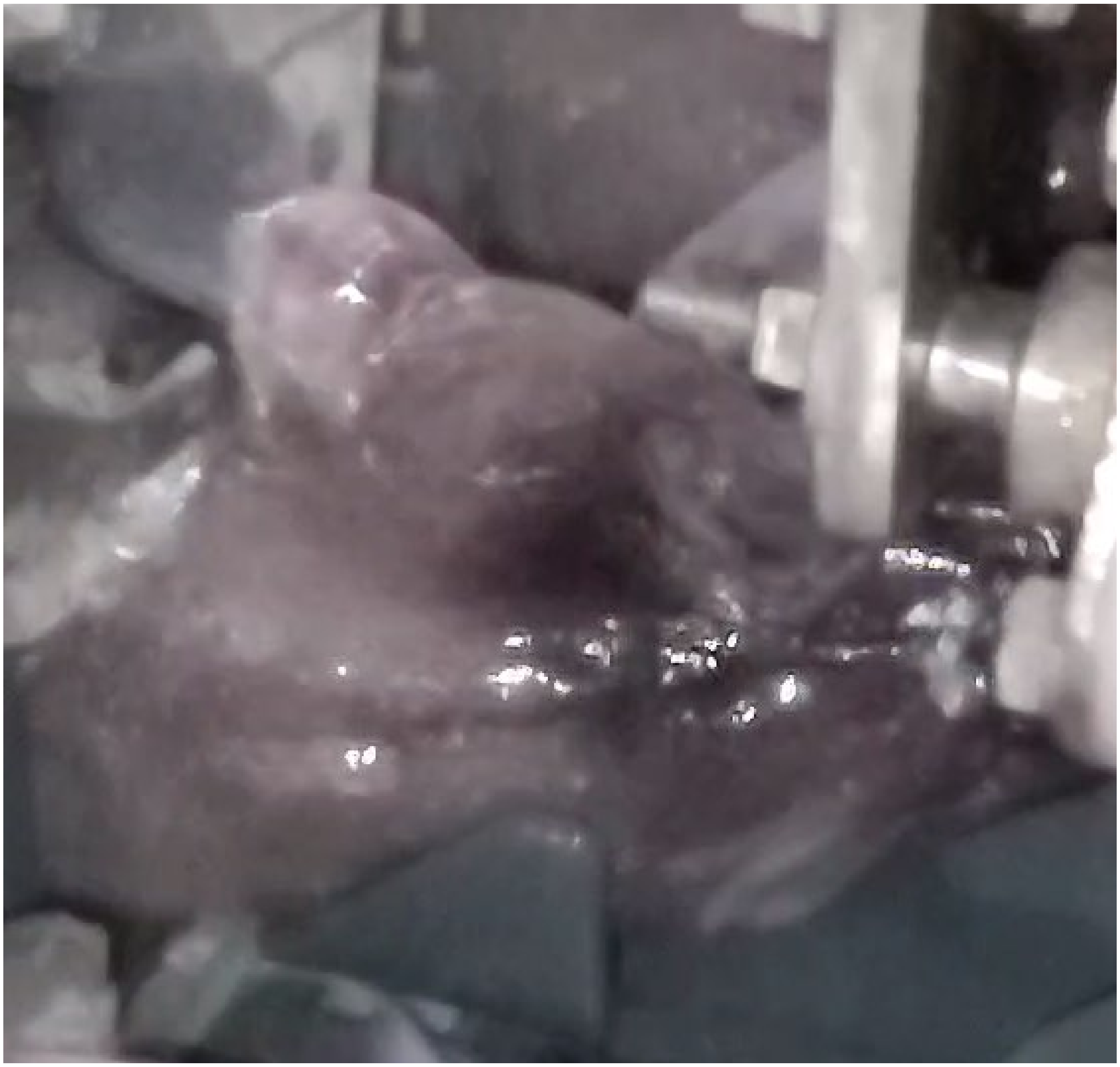

Figure 13.

A fish head being crushed by the head pusher.

Figure 14.

The red circle is the spring-loaded shaft that compresses opposed to the fish.

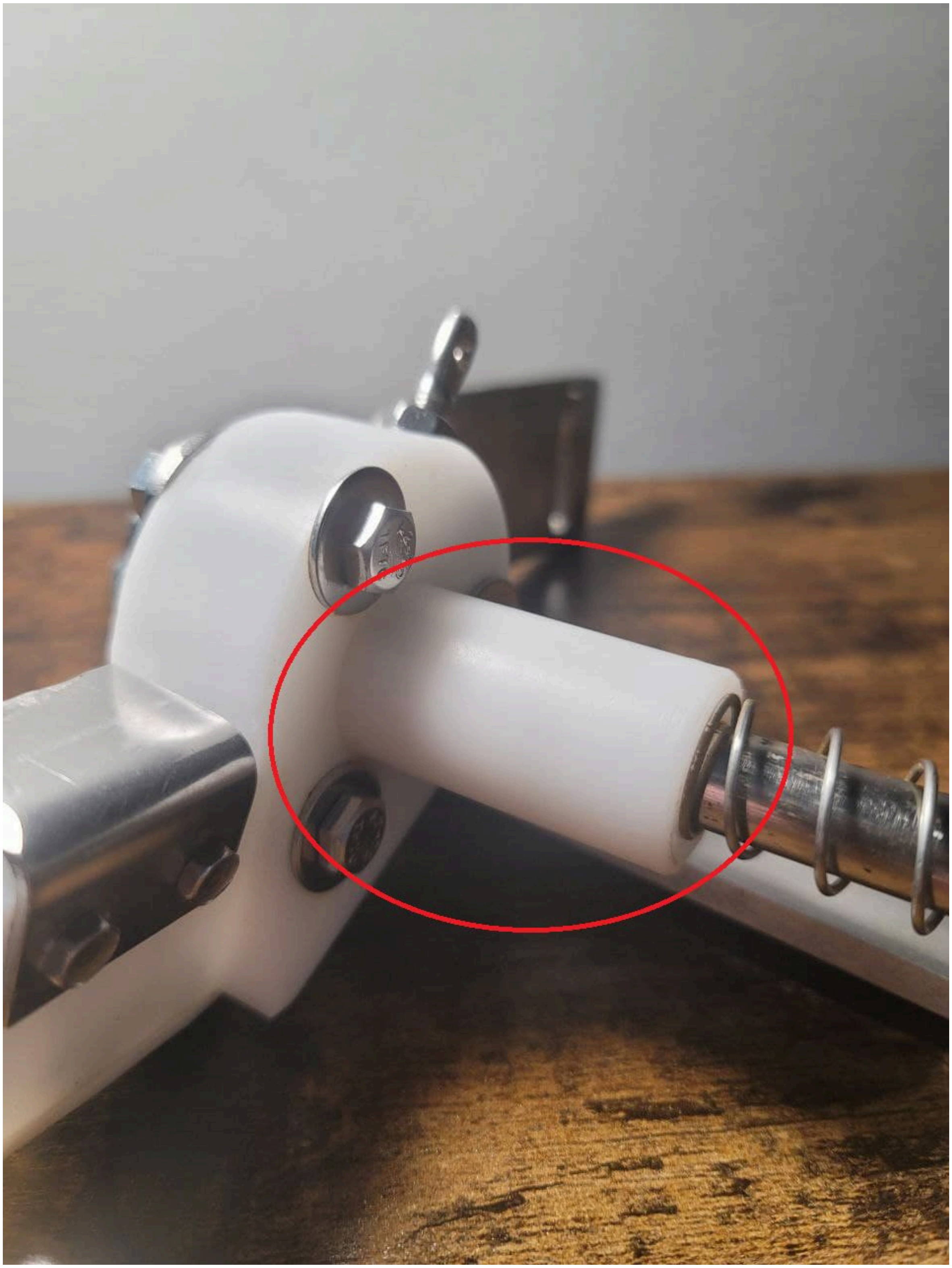

Figure 15.

Circled is the press-fit bushing that glides along the 8mm shaft.

Figure 16.

Carcass removal location from the 212-recovery test.

Figure 17.

How the fish were aligned for the recovery test. The size and shape of the fish were approximately the same for every trial, with slight variations in total mass. Smaller fish were chosen as errors can be hidden easier in the larger fish.

Figure 18.

Marel M1100 Scale was used for all testing. This scale can anticipate changes in gravity, making it exceptionally accurate for testing down to 1/100th of a Kg during rough weather.

Figure 19.

Pre removal of guts, the example is from the head end of the fish

Figure 20.

Post removal of guts for consistency of testing

Figure 21.

Example of how a test basket of fish was weighed after removing the head and guts.

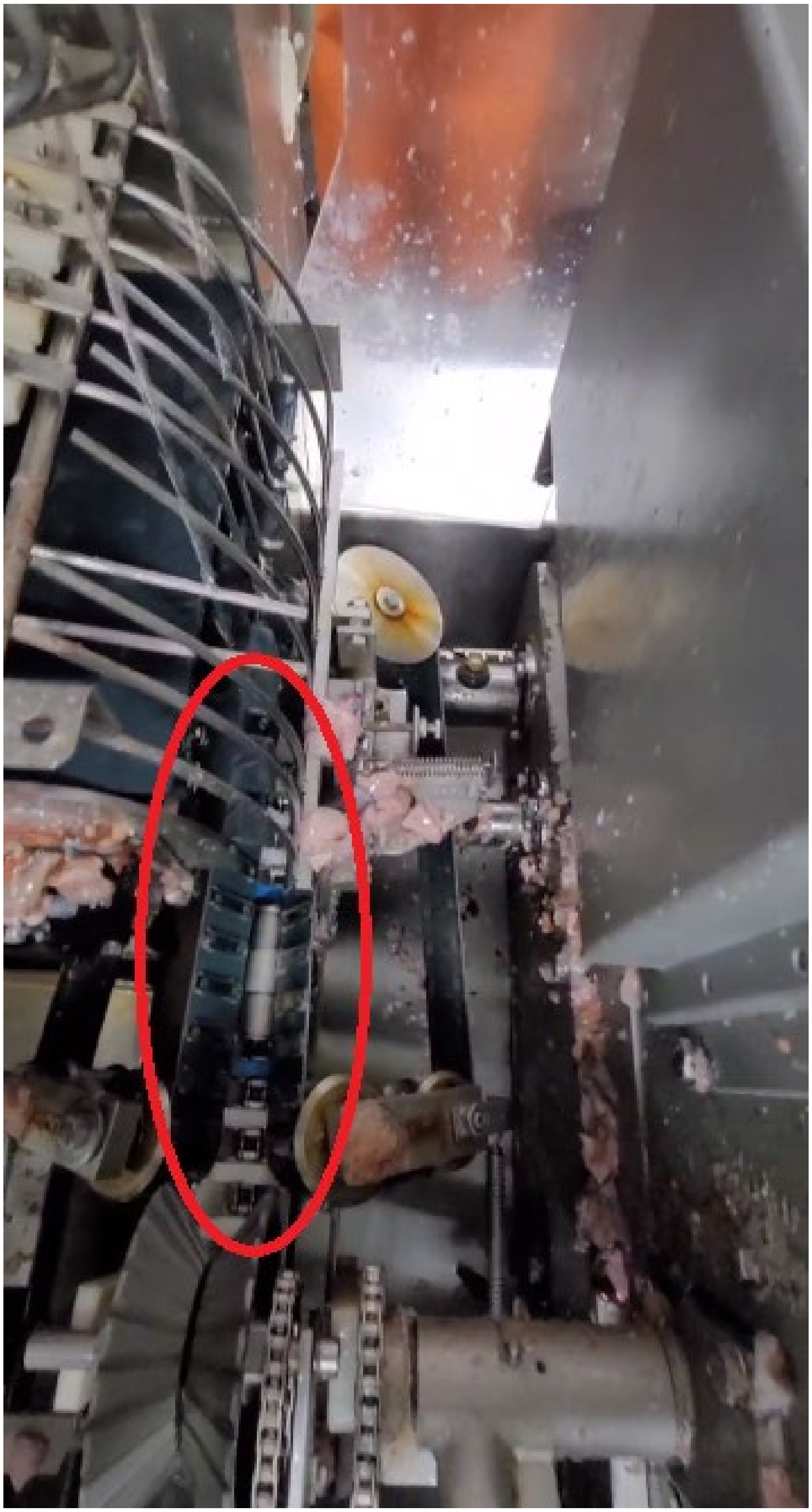

Figure 22.

Segment Chain circled and "The Drop" to get there from the green trays above.