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Automated Pinbone Removal in Cod and Whitefish

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Authors:
Kristin Anna Thorarinsdottir and Kristjan Hallvardsson (eds.)

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Nordic Innovation, Stensberggata 25, NO-0170 Oslo, Norway
Phone: (+47) 22 61 44 00. Fax: (+47) 22 55 65 56.
E-mail: info@nordicinnovation.org
www.nordicinnovation.org

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Nordic Innovation
Stensberggata 25,
0170 Oslo, Norway
Phone: +47 47 61 44 00
info@nordicinnovation.org
www.nordicinnovation.org

Marel
Austurhraun 9
Gardabaer
IS-210 Iceland
Phone: +354-563-8000
info@marel.com
www.marel.com

Faroe Origin
Fiskivinnuhavnin 1
600 Saltangará
Phone: +298 200600
origin@origin.fo
www.faroeorigin.fo

Norway Seafoods
Postboks 1301, Vika
0112 Oslo
Phone: +47 76 06 20 00
forbruker@norwayseafoods.com
www.norwayseafoods.com

Stiftelsen SINTEF
Postboks 4760 Sluppen
7465 TRONDHEIM
info@sintef.no
Phone: +47 73 59 30 00
www.sintef.no

Project participants

Iceland
Marel
Kristján Hallvarðsson
Director of Product Development
Kristjan.Hallvardsson@marel.com

Faroe Islands
Faroe Origin
Jens Pauli Petersen
Chief Executive Officer
jensp@origin.fo

Norway
Norway Seafoods
Rami H. Khoury
Managing director
Rami.Khoury@norwayseafoods.com

Stiftelsen SINTEF
Helene Schulerud
Senior scientist
Helene.Schulerud@sintef.no

SINTEF RM
Tone B. Gjerstad
PhD Forsker
Tone.B.Gjerstad@sintef.no

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Executive summary

Main objective

The main objective of the project was to develop a technology and equipment to cut pinbones from fish fillets by automatic means.

Pinbones are a series of bones in fish fillets, located at the most valuable part of the fillet. These bones are usually removed from the fillet by manual cutting. This manual operation is labor intensive, tedious, and requires skill that takes time and practice to develop.

It is critical that the cutting operation (whether manual or automatic) does not leave any bones or bone fragments in the fillet. At the same time, it is important to minimize the amount of high-value raw material that is cut away with the pinbone removal.

Implementation

The technology needed to enable automatic pinbone removal was twofold. Real time X-ray system was developed to accurately locate the bones in each fillet. Secondly, a cutting mechanism was designed and constructed. This mechanism follows the trajectory of the pinbones in each fillet, based on the X-ray measurements.

The project partners formed an ideal consortium for this work. Marel has long experience in developing advanced equipment for cutting, X-ray inspection, robotics, real time control, software and integrated system design for fish processing.

SINTEF ICT and SINTEF RM contributed to the work with scientific and engineering knowledge and support in the fields of X ray imaging, cutting and mechanical handling.

Norway Seafoods and Faroe Origin participated as end users and by overseeing the work so that the results can be readily applied by the fish processing industry.

Finally, the technology has been tested under real life conditions, in collaboration with different processing plants in Iceland.

Deliverables

One of the main deliverables of the project is FleXicut, a system that incorporates two critical processing steps in one machine: precisely locating the pinbones and then cutting the fillet to remove them.

The FleXicut uses the latest X-ray technology to locate pinbones with extremely high accuracy, down to 0.2 mm. Determining the orientation of the bones is critical in order to cut out less flesh and leave more on the loin.

The water-jets used for the bone removal process are very flexible, enabling the FleXicut to perform a variety of cutting patterns. The angle cutting option allows it to follow the curved lines of the bone frame very closely. This means significant yield gains in the loin – the most valuable part of the fish.

With the X-ray scanning and water-jet cutting performed on the same belt, there is no risk of movement between the bone detection and cutting processes, which ensures a superb level of cutting accuracy based on the bone location. Furthermore, the machine is equipped with blade which easily trims the tail, when needed.

Future perspectives

The new level of automation aimed for by this project is of great importance for the fish industry. The new technology will result in better yield and quality of the valuable raw material, reduced risk of bones in the final product and increased overall automation, which is particularly important for the global competitiveness of fish processing in the North Atlantic region.

Overview of work packages

Work package 1: Specification and overall concept (for whitefish processing)

The purpose with this work package was to specify the requirements and overall concept of the process system to be developed within Apricot (hereafter referred to as FleXicut). The focus was on following issues:

- **Raw material.** Discussion and analysis of the raw material to be considered for the process.
- **Process overview.** Overall explanation of the present process and the proposed new processes (with and without superchilling).
- **Fillet treatment before pinbone removal**. Evaluate the pre-trimming actions needed.
- **Location and size criteria for pinbones.** Review specifications for bone-free products.
- **Cutting of pinbones from the fillet.** Establish knowledge on bone location and alignment in fillet, which will be used to guide cutting profiles, thus removing minimum of flesh with bones.
- **Fillet portioning.** Discuss current patterns in fillet portioning, in relation to design of FleXicut and potential functions of the process system.
- **System specifications.** Decide on system requirements and functions to include.

Work package 2: Automated pinbone localization

Numerous X-ray components were compared during a series of tests at SINTEF in Oslo in August/September 2012, and further tests were concluded in May 2013. SINTEF worked on the development of means to estimate the 3D location of pinbones in fish fillets, and on algorithms for automatic pinbone detection, with background material and in consultancy with Marel. Decision on X-ray components and approaches for the prototype in factory tests was made in 2014.

Work package 3: System integration and prototype development

A mockup was designed and constructed during the first quarter of 2013. This unit was equipped with the cutting devices, controllers and X-ray scanning. It was tested at Marel.

A prototype, suitable for factory tests, was designed and constructed in fall of 2013. It was a combination of high resolution X-ray and cutting technologies (water jet for removal of pinbones and blade for tail trimming).

Work package 4: System testing

The first 0-serie for running in factories was constructed during end of the year 2014 and early 2015. Valuation of throughput and processing yields was conducted and compared to manual procedures. The system was evaluated by SINTEF in February 2015. Development of the FleXicut has continued in 2015, resulting in broader range of cutting patterns (for portioning of the fillet parallel to bone removal), higher yield and increased throughput.

Further details from the project are outlined in the following pages.

1. Work package

1.1. Initial specification and overall concept

The purpose with this work package was to specify the requirements and overall concept of the process system to be developed within Apricot (hereafter referred to as FleXicut).

1.1.1. Raw material

In the development of the system, it was decided to focus on the following fish species:

- Atlantic Cod. Sizes: 1kg to 6,5kg (head on and gutted).
- Atlantic Saithe. Sizes: 1kg to 6,5kg (head on and gutted).
- Atlantic Haddock. Sizes: 0,75kg to 3kg (head on and gutted).

These are among the main wild caught demersal species, with regard to catching and consumption volumes in Europe, where cod is the no. 1 whitefish species. In 2010 (when planning the project), 138 thousand metric tones (MT) of cod were caught by EU-fishing vessels, whereas 822 thousand MT (live weight) were imported from other countries, such as the following (the figures may not be totally comparable, because processing may differ prior to weighing):

- 302 thousand MT from Norway
- 197 thousand MT from Iceland
- 37 thousand MT from Faroe Islands
- 83 thousand MT from Russia
- 126 thousand MT from China[1]

In March 2015, FleXicut had proven to be successful process system for pinbone removal from cod, saithe, haddock and wolffish fillets.

1.1.2. Current fish processing

An example of typical approach to current fish processing is shown in Figure 1. Prior to manual trimming and cutting, a number of operations are made on the fillet (scaling, de-heading, filleting, skinning). They apply to production of both fresh (chilled) and frozen products, and whether the raw material is fresh or has been frozen and thawed before processing. The operations are detailed further in the section “Fillet treatment before pinbone removal”.

[1] A.I.P.C.E.-C.E.P. 2011. FINFISH STUDY 2011. EU Fish Processors and Traders Association. Brussels, September 2011. www.fiskbranschen.se/FinFishStudy2011.pdf (02.05.2012)

When the fish is de-headed, the cut is made behind the collar bone which remains with the head, and the cut may be angled to remove varying portions of the belly flaps. These are the side walls of the belly cavity. The flap is usually still attached to a fillet when the fillet is removed during filleting of the fish; also called flap, lug flap, wing.

Cutting roughly parallel with the backbone by filleting machine, results in a slice of largely boneless flesh from along the length of a fish i.e. the fillets. The amount of belly flap left on the fillet depends on the way in which the fish was gutted or headed and gutted and the way in which the fillet is subsequently trimmed. Furthermore, the settings of the filleting machine can influence the amount of flesh removed from the belly flap, when scraping off ribs and membranes from the belly cavity.

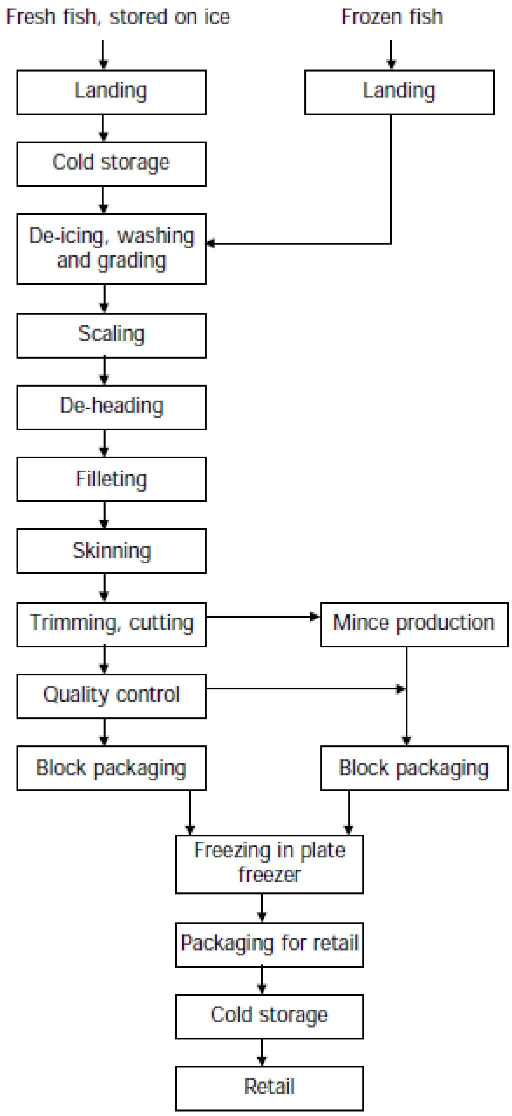

Figure 1. *Example of flow diagram of existing processes for filleting of whitefish[2], in processing of frozen products.*

[2] UNEP. 2000. Cleaner Production Assessment in Fish Processing. Prepared by COWI Consulting Engineers and Planners for the United Nations Environment Programme and Division of Technology, Industry, and Economics, Denmark. Miljøstyrelsen. www.unep.fr/shared/publications/pdf/2481-CPfish.pdf (02.05.2012)

After filleting (and skinning), trimming is carried out to remove defects and parts of the fish that do not comply with specifications of the product. For example, the belly flap may be removed. Pinbones and the walking stick (Figure 2), which are intramuscular bones, are removed in the trimming step. The pinbones are aligned within the connective tissue sheaths (myosepta) which segmentally separate adjacent muscle blocks (myomeres). In cod, the pinbones extend from the rib bones towards skin, in a layer of connective tissue which is located between belly flap and loin. Traditionally, the pinbones have been removed manually by the workers who perform trimming. It is typically done with a narrow cut on both sides of the pinbone row. This cut, which is referred to as a V-cut, should preferably be as close to the pinbones as possible, with minimum amount of flesh cut and removed along with the bones.

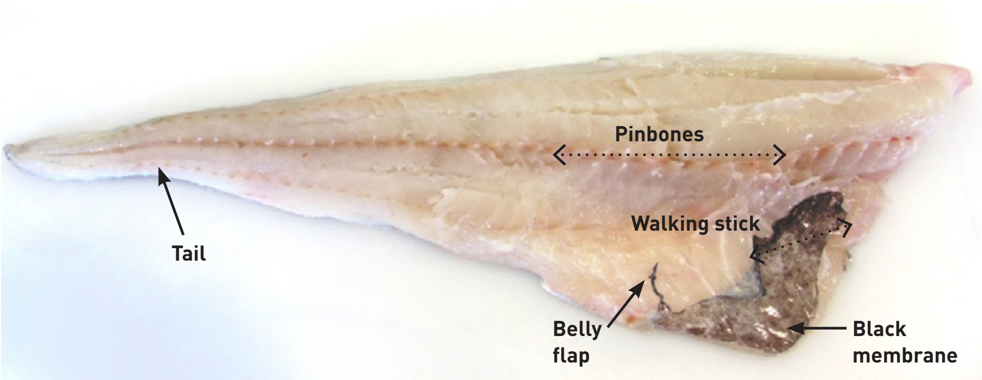

Figure 2. *A fish fillet before pre-trimming for removal of bones, parasites (nematodes/roundworms)) and possible blood stains.*

The "walking stick" extends from the pectoral fin into the belly flap. It is removed manually from the fillet during trimming as the pinbones. The removal might become an optional function in FleXicut depending on yield requirements and portioning patterns of each producer. Example of area that could be removed with the walking stick is indicated with blue dashed line (Figure 3). The location of the pinbone row is indicated by green dashed line.

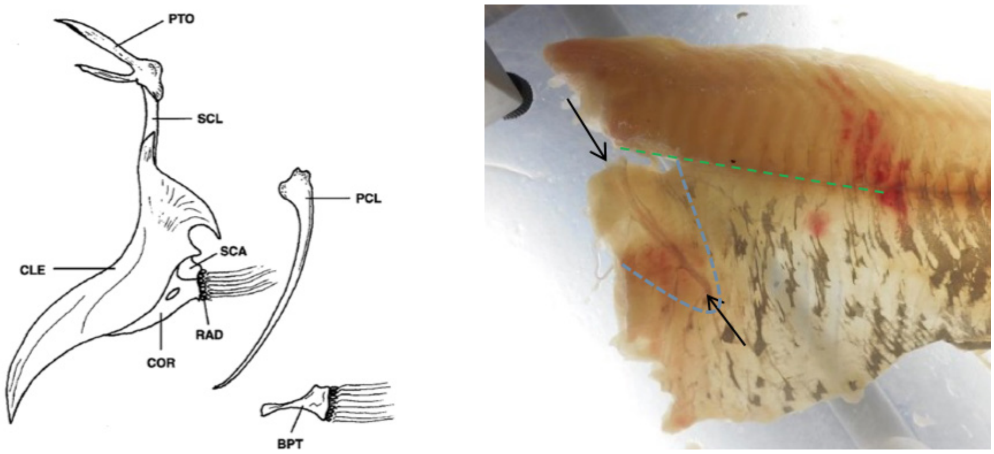

Figure 3. *Pectoral and pelvic girdle of a gadoid fish. BPT, basipterygium; CLE, cleithrum; COR, coracoid; PCL, postcleithrum bone ("walking stick") ; PTO, posttemporal; RAD, radials; SCL, supracleithrum; SCA, scapula (to the left).[3] Alignment of walking stick in cod fillet indicated by black arrows to the right.*

[3] Watt J, Pierce GJ, and Boyle P. 1997. Guide to the Identification of North Sea Fish Using Prernaxillae and Vertebrae. ICES COOPERATIVE RESEARCH REPORT No. 220. Copenhagen, International Council for the Exploration of the Sea.

1.1.3. Product quality defects

Quality defects are "terms with particular meaning in quality control, especially in the sampling and testing of products for compliance with specifications. A defect is a failure in an item to comply with one or more criteria in a specification. For example, a specification for boneless, skinless fillets might require the weight of the fillets to be within a stated weight range. If a particular item in a sample of a batch of fillets is outside of this range then there is a defect in that item. An item can have more than one defect. Using the fillets specification as an example, a fillet might fail on criteria for weight, presence of bones, blood spots and presence of skin. One or more defects in an item will render that item defective, that is, not complying with the specification."[4]

None of the defects listed here should be present after trimming:

- De-heading defects (reason poor de-heading)
    - Collar bone (Icelandic: „Klumbubein")
    - Neck bone (Icelandic: "Hnakkabein")
- Filleting defects (due to poor filleting)
    - Pearlstripe
    - Membranes (peritoneum)
    - Bones from the „skeleton" or backbone (vertebra)
    - Fins (including tail fin)
- Skinning defects (due to poor skinning)
    - Skin remains
    - Membrane under skin
- Quality defects (either by handling or other quality aspects)
    - Parasites
    - Blood spots / bruises
    - Blood veins
    - Loose bones

1.1.4. Location and size criteria for pinbones

The fish consumer market has various references for bone size acceptance. One is the Codex, which is a general reference used by some of the industry, but others have defined their own references which are more critical than the Codex. It is essential that the proposed system removes at least the bones specified by the Codex, and preferably smaller ones as well.

1.1.4.1. Codex

The Codex specifies that batches are unacceptable that contain more than one bone per kg of product greater or equal to 10 mm in length, or greater or equal to 1 mm in diameter; a bone less than or equal to 5 mm in length, is not considered a defect if its diameter is not more than 2 mm. The foot of a bone (where it has been attached to the vertebra) shall be disregarded if its width is less than or equal to 2 mm, or if it can easily be stripped off with a fingernail.

From CODEX STAN 165-1989 chapter 8,4 BONES (IN PACKS DESIGNATED BONELESS): More than one bone per kg of product greater or equal to 10 mm in length, or greater or equal to 1 mm in diameter.
A bone less than or equal to 5 mm in length, is not considered a defect if its diameter is not more than 2 mm.

[4] Whittle and Howgate. 2002. Glossary of Fish Technology Terms. Fisheries Industries Division of the Food and Agriculture Organization of the United Nations

The foot of a bone (where it has been attached to the vertebra) shall be disregarded if its width is less than or equal to 2 mm, or if it can easily be stripped off with a fingernail.

1.1.4.2. Individual company standards

Individual processing firms may have their own standards for bone content, which are usually stricter than the Codex. In the case of Norway Seafoods, they take typically over 10.000 samples per month, each sample weighing 200 grams, for bone content inspection. Their reference is that there should be no more than 0,065 bones per kg or 1 bone per 15,4 kg.

Measuring the pinbone dimensions is not trivial. The length of a curved bone may be taken along its curvature or simply straight between end points. Furthermore, the diameter of a pinbone may vary from one end, through its center, and to the other end. In this project the length measurements will be made along the straight line segment from one end of the bone to the other. The diameter will be measured at the center of the bone, which is usually the thickest part.

1.1.5. Future fish processing

The proposed future fish processes, including the invention from the APRICOT project, are illustrated for the non-superchilled process in Figure 4 and for superchilled process in Figure 5. The main focus of this project, automatic pinbone localization and cutting, is highlighted by the red dashed frame in the figures. Development of automatic quality control (QC) equipment is not within the scope of the APRICOT project but is considered an important feature of future fish processing.

1.1.1.1 *Step 1: De-heading, Filleting and Skinning*

The output of this step is fillets. For de-heading, filleting and skinning, existing technology was used and in that sense it was not a part of the Apricot project.

1.1.5.1. Step 2: QC detection

Information on the percentage of fillets with defects, the type of defects and the degree of trimming needed, have been collected. Thereby an estimate of the benefits of grading and sorting fillets by defects will be established, i.e. whether the fillets can be trimmed on active flow trimming lines (minor defects) or trimming stations are needed. With active trimming the trimming is made directly on the conveyor belt while the belt is running. Thus, minimizing handling of the fillet compared to the other model where the fillet is taken from the conveyor belt and trimmed on a plate and replaced on another conveyor belt afterwards. Automation of QC and modification of trimming lines will be part of other projects.

1.1.1.2 *Step 3: Pre-trim*

As a fish fillet enters the automatic pinboning equipment, the fillet is expected to be properly prepared and free of all defects, with only the pinbones remaining. This will involve pre-trimming before pinbone detection and removal.

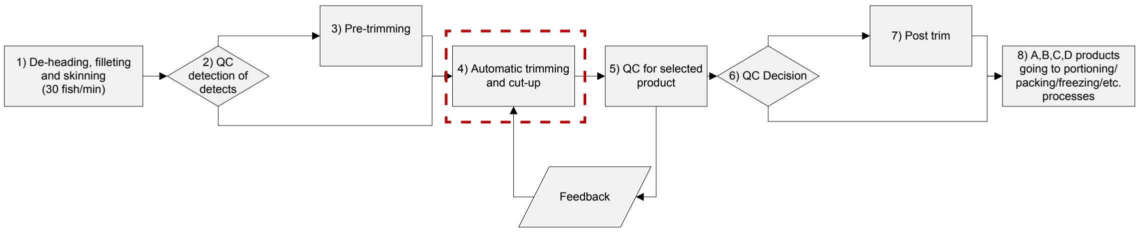

Figure 4. *A block diagram of the non-superchilled process. The automatic pinbone localization and cutting is highlighted in the red dashed frame.*

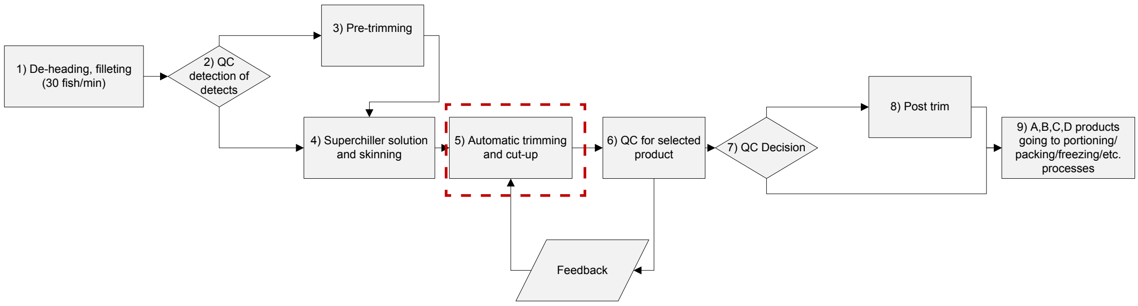

Figure 5. *A block diagram of the superchilled process. The automatic pinbone localization and cutting is highlighted in the red dashed frame.*

1.1.5.2. Step 4: Automatic trimming/ pinbone removal

The main objective with the APRICOT project was to automate the removal of pinbones. Other achievements are increased throughput in the trimming step (kg per man-hour), primary yield and value of products. Higher throughput during trimming has been achieved as the number of actions needed during trimming fillets prior to processing by FleXicut is lower than in traditional processes. The trimming rate of the operators is also assumed to be higher with simpler process. The material flow is more continuous and less handling of raw material and products is needed. Therefore, the risk quality defects such as gaping, is decreased.

One of the optional functions in the working series, is to split the fillets up into different portions (tail, loin, centre and belly flap). This was not a direct part of Apricot, but has evolved during the project lifetime. Automatic splitting in FleXicut saves labour and handling, and is therefore beneficial for the producers. The main cutting patterns of FleXicut, are briefly discussed later in this report.

1.1.5.3. Step 5: QC inspection

Potential methods for automatic QC inspection are x-rays and/or spectral techniques. The need for automation of QC has been discussed with stakeholders within the fish processing industry during the lifetime of APRICOT. The FleXicut system can be used as inspection tool for bones remaining in the fillet after pre-trimming. With further modification of the software, it could possibly be used as tool for evaluating gaping and accordingly decide on how each individual fillet should be portioned. Other methods, such as spectral imaging are needed for evaluation of blood and nematodes within the fillets. Grading of fillets, with regard to quality parameters such as gaping are among activities planned in forthcoming projects, in collaboration between Marel, research bodies and partners from the fish industry.

1.1.5.4. Step 6: Decision and step 7: Post Trim

Any failures occurring in trimming and/or pinbone removal, have to be corrected by post trimming. The QC may include that the product is automatically diverted to post trimming, depending on the inspection technique used. As QC may not necessary contain all measurement methods necessary, manual QC may also be needed.

1.1.6. APRICOT process with superchiller

The processing steps are that same as for the process without superchiller, except that superchilling is added prior to skinning.

1.1.6.1. Superchilling

The super chilling technique used within the project, was developed by Skaginn. It is a combination of brine spraying (immersion) and superchilling of the fillet in a freezing tunnel. The skin side of fillets is chilled on a Teflon coated aluminium conveyor belt at a temperature of approximately -8 °C and simultaneously blasting cold air over the fillets, lowering fillet temperature down to -1 °C.

Experimental work with superchilled cod fillets by FleXicut, showed that quality of the cut and accuracy of cutting was similar as for chilled fillets. Processing of salmon fillets indicated that the quality of cut through the skin was better when the fillets had been superchilled prior to water jet cutting.

1.2. Modification of process, including FleXicut

1.2.1. Pre-trimming of fillets - treatment before pinbone removal

The trimming step was modified to become a pre-trimming step before FleXicut. Overall, the same operations are performed except the pinbones are left within the fillet to be removed by FleXicut.

Information was collected during the project on the characteristics of defects and the ratio of fillets with defects. These will be used for decision making in future development. For example, whether the material flow will be divided into two streams depending on whether the fillets can be pre-trimmed on active flow trimming lines (minor defects) or trimming stations are needed. Automatic quality grading and sorting system would be required to enable steering of the material flow (after filleting and skinning) with regard to trimming operations needed.

1.2.2. Pinbone scanning to guide pinbone removal

In FleXicut, X-ray scanning of the fillets is used to localize the pinbones in real time and estimate orientation of the bones. Several approaches have been tested, including optimization of sensor design and placement. The X-ray technology is capable of detecting fish bones within the size criteria of the industry. Based on the localization of the pinbones, the software algorithm calculates the desired cut pattern. The detection rate and processing of data is sufficient to scan the entire pinbone lineup, process the images, detect the pinbones from the background, and deliver the desired coordinates for cutting. The software is adjustable, designed to cope with varying condition of the raw material and changes in bone orientation due to processing.

1.2.3. Pinbone removal by cutting and portioning

Water jet cutting, was chosen as the method for removing the bones, as it can easily follow the curvature of the pinbones to minimize yield loss. The water nozzles are activated accordingly to cut the fillet for bone removal and portioning. The latest version of FleXicut has extra blade sets for tail trimming and additional porting options. Several cut patterns are available and can be selected by the operator. Cutting patterns may vary between processors, different partterns are shown in following sections.

1.2.4. Fillet portioning

The primary cut of fish fillet to remove pinbones, is the V-cut. It involves cutting along both sides of the pinbone strip, leaving most of the belly flap. The cuts meet just behind the position of the last pinbone. The V-shaped cut contains the pinbones and is removed from the fillet. The proportion of fillet removed by V-cutting varies according to the species and degree of skill and experience exercised in cutting. Manual V-cuts may range from 4 to 15% for roundfish such as cod, haddock and whiting, depending on the condition of the fish and the skills of the person cutting the fillet. For cod the typical yield loss is around 8%, when cut by hand.

An alternative to V-cut is the J-cut, which is a simpler cut but results in considerable lower yield, since both pinbones and belly flap are removed. A cut is made through the fillet from the neck end of the fillet, dorsal to and along the line of pinbones towards the last pinbone, and then curved sharply down to the ventral edge of the belly flap.[5]

In addition, various cutting patterns (Figure 6) are used for bone removal and portioning, depending on market requirements and condition of raw material. The ones shown below are among the different patterns that will be optional in FleXicut.

Figure 6. *Examples of portioning profiles used in the whitefish industry*

1.2.5. QC bone inspection using X-ray vision

The FleXicut can be used to detect bones that should have been removed by pre-trimming, such as neck bone, rests of backbone and fins. Thus the fillets can be diverted to post-trimming, after pinbone removal, when needed. The X-ray technology could be applied as a separate unit at the end of the processing system for quality control, scanning the fillets for remaining bones or bone fragments. However, it can not be used for inspection of defects such as blood or nematodes. Currently, these are monitored manually.

5 Whittle and Howgate. 2002. Glossary of Fish Technology Terms. Fisheries Industries Division of the Food and Agriculture Organization of the United Nations

2. Work package

2.1. *Development of X-ray system for bone detection*

Extensive tests were carried out at SINTEF with various X-ray sources and X-ray sensors, to determine which components gave best images and detection of smallest fishbones. Test items were made from plastic material, to obtain comparison of the detection capability for fish bones (Figure 7). Bones were removed from cod fillets, measured (length, diameter at the center and diameter at the thin end (Table 1) and lined up and glued to a plastic block, as shown in the following images. An X-ray image of the bones on the plastic block is shown here, where the bones were labelled 1-10, from left to right (Figure 8). For comparison, a few aluminum wire bits were placed with the bones. Furthermore, work was carried out to assess different approaches to estimate the three-dimensional location of pinbones in the fillets.

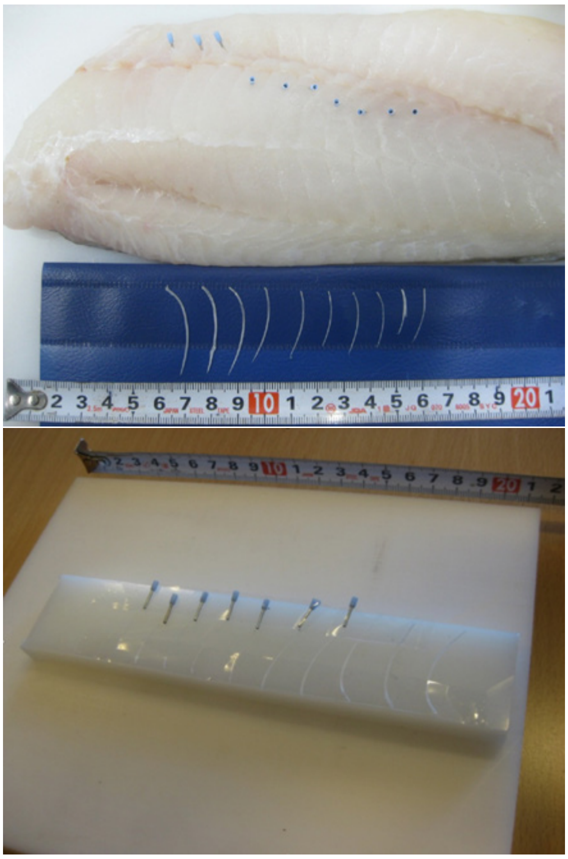

Figure 7. *Test items made from plastic material, to obtain comparison of the detection capability for fish bones.*

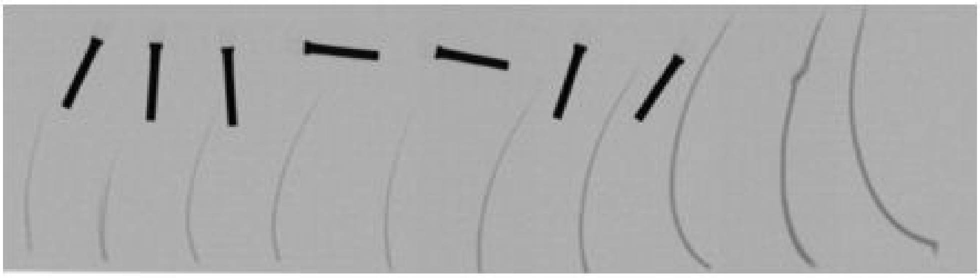

Figure 8. *An X-ray image of the bones on the plastic block is shown here, (bones e labelled 1 to 10, from left to right). For comparison a few aluminum wire bits were placed with the bones.*

Table 1. The dimensions of the bones used to for the test item.

Bone number	Length	Diam. center	Diam. thin end
1	22 mm	0,4 mm	0,1 mm
2	18 mm	0,4 mm	0,1 mm
3	21 mm	0,4 mm	0,1 mm
4	24 mm	0,4 mm	0,0 mm
5	20 mm	0,3 mm	0,1 mm
6	25 mm	0,4 mm	0,0 mm
7	27 mm	0,5 mm	0,2 mm
8	32 mm	0,6 mm	0,3 mm
9	32 mm	0,7 mm	0,4 mm
10	34 mm	0,8 mm	0,5 mm

2.2. *Development of algorithms and guiding software*

SINTEF and Marel collaborated in developing algorithms and software to localize pinbones in real time and to guide the water jet cutting for bone removal.

Design of a 3D imaging solution was one of the sub tasks within the project. Project results revealed to high resolution 2D imaging would give sufficient information for precise localization of the bones at lower costs than by 3D imaging. Higher number of sensors would be needed to achieve 3D positioning, increasing the cost of the equipment significantly. Therefore, the imaging solution used in FleXicut is a 2D one.

For optimization of the performance of the software developed, some amount of knowledge of fish anatomy has been integrated into the software, in order to increase the robustness of the software.

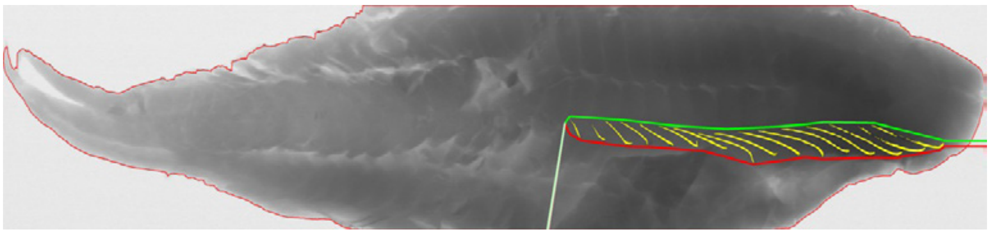

Figure 9. *An X-ray image of a typical cod fillet, where pinbones have been automatically detected and highlighted in yellow.*

3. Work package

3.1. System integration and prototype development

A mockup of an integrated pinbone cutting machine was ready for in-house experimentation and testing at Marel in 2013. This unit was used for testing at Marel and in fish processing plants. Various settings of water cutting were tested for cod and salmon in different conditions and for different products types, to investigate the relationship between following parameters:

- Settings of water jet cutting
- Pressure of water
- Nozzle diameter
- Cutting rate
- Cutting direction (transverse/longitudinal cut of fillet)
- Cutting position on cod fillet (e.g. thick/thin parts, loin vs tail)
- Condition of the raw material (chilled vs. superchilled)
- Product type (skin on or skinned fillets)

Part of the trials was conducted by a M.Sc. student (Helga Franklínsdóttir), in collaboration with the University of Iceland and Matís Ltd. - Icelandic Food and Biotech R&D.

The main criteria for success at that stage, was the cutting efficiency and edge quality (clean slice). Cutting efficiency was a measure of how well the water beam was able to cut through muscle, connective tissue and skin. Edge quality was a visual evaluation of how clean slicing of the fillet was. In addition, the degree of "cutting dust" which was presumable formed by turbulence during water jet cutting was estimated. This was mainly seen when cutting through the thickest parts of the fish. In later versions of FleXicut this parameter was not in issue in the processing of whitefish.

Figure 10. *Water jet cutting salmon and cod fillet. "Cutting dust" is clearly visible for both species*

Water pressure and cutting rate, were essential for cutting efficiency, i.e. cutting through muscle, connective tissue and skin. The proportion of connective tissue which is high in the tail part, was very critical for cutting efficiency, especially for cod fillets. It was more difficult to cut completely through the connective tissue and obtain a clean slice than to cut through the skin in that part of the fillet. For the ranges of settings tested, the cutting rate was the most important factor when it came to quality of cut since sawdust increased in fillets with increasing rate.

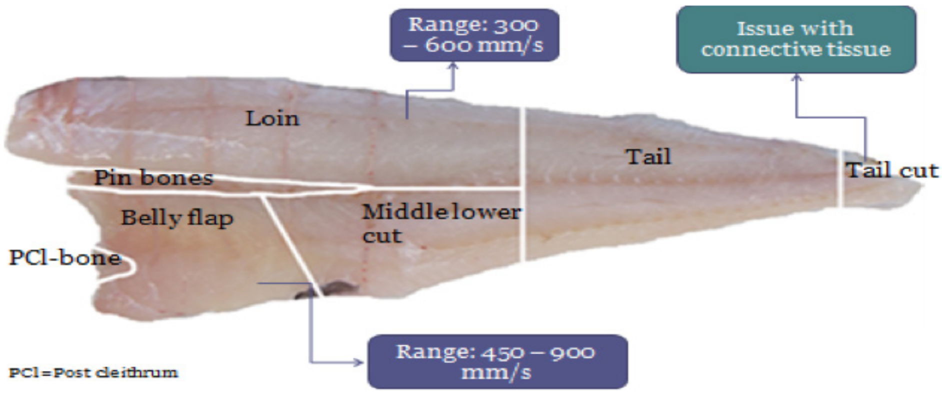

Figure 11. *Range of cutting rate for different parts of the fillet. Higher cutting rate could be applied for thinner parts of the fillet, i.e. belly flap. High ratio of connective tissue in tail caused problems in water jet cutting. (Helga Franklínsdóttir, 2014. M.Sc. Project in Food Science at the University of Iceland).*

Super-chilling prior to cutting resulted in cleaner slicing and less sawdust, particularly for salmon. However, it was not a perquisite for cutting efficiency.

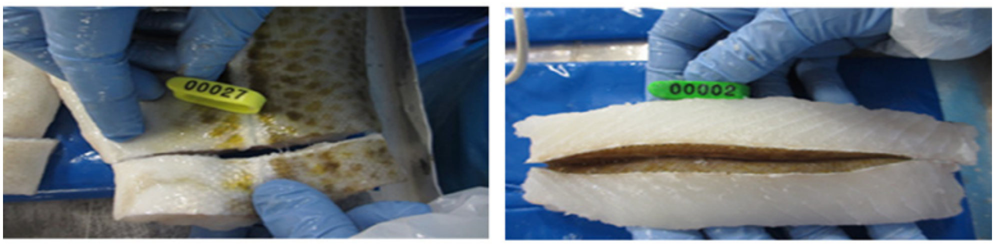

Figure 12. *Water jet cutting of superchilled cod, on the left, the different fillet parts are still slightly attached by connective tissue (within the myosepta) (Helga Franklínsdóttir, 2014. M.Sc. Project in Food Science at the University of Iceland).*

In the first prototype another type of nozzle type was used, giving more focused and narrower water beam. This along with other adjustments resulted in high edge quality. Furthermore, blade cutting used for tail trimming solved issues related to high ratio of connective tissue within the tail.

4. Work package

4.1. System testing

A prototype machine was designed and ready for first tests at the end of 2013. In the X-ray sensing unit (located at the left on machine on picture), the fillets are scanned to locate the bones, then moved into the cutting unit which uses multi-axis cutting mechanisms to cut the bones from the fish fillet. After initial in-house tests at Marel, the machine was taken for factory tests during 2014, where performance in practical production environment was evaluated.

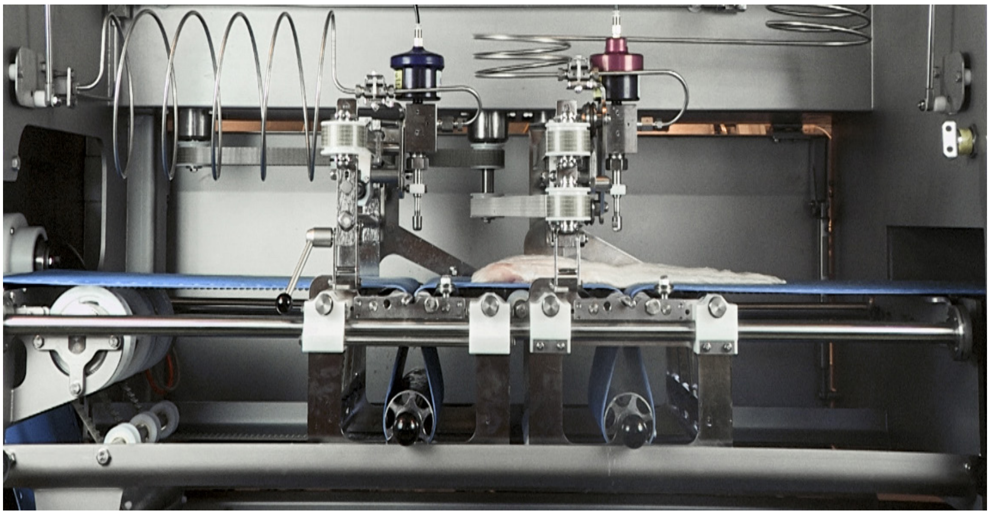

Figure 13. *The prototype of the automatic pinbone cutting machine developed in the APRICOT project.*

The first 0-serie of FleXicut was installed in another processing plant in January 2015. Another version was presented at the Seafood Expo Global in Brussles, Belgium, in April 2015.

4.2. Evaluation of performance under industrial conditions

The performance of the prototype under industrial conditions was evaluated by Sintef. In following table, the key parameters of the system and their limits of operation are outlined according to specifications defined within work package 1. The column specifying „practical / objective" figures contains those values that were considered to be realistic to reach in the project, while the column „ideal / ultimate" shows the ideal values that may or may not be realistic with the available technology. All of these were subject to change as the work progressed.

The capacity in terms the number of fishes/min depends on fish size. A better measure, is how the systems meets the processing capacity of a filleting machine. The processing capacity of FleXicut meets the processing capacity of one filleting line, as generally operated in processing plants today.

The system meets the requirements set for fillet size. FleXicut can cope with up to 2.5 kg fillets (10 kg fish, gutted with head). The weight of the smallest fillets can be from 250g.

FleXicut can detect and remove pinbones down to 0.1 mm in diameter and 14 mm length and 0.2 mm width and 7 mm length. This result is within the initial objective for the machine (tested by SINTEF in February 2015).

The average pinbone removal is within the limit of the ideal objective of 6% (tested by SINTEF and also observed in tests performed by Marel employees).

FleXicut can cope with raw material in different condition. The gaping level has stronger influences on the portioning options, i.e. what kind of products can be made from the fillet rather than bone removal by FleXicut.

In general, it can be concluded that the requirements set at project start have been met, regarding bone detection, bone removal and processing capacity. Furthermore, the project work has led to several spin-offs and development of other units for increasing automation in the whitefish industry, such as new flow line (pre trimming/ removal of processing defects and defects present in raw material), development of fillet portioning by FleXicut (Figure 15), systems for splitting and sorting of different products and packing (Figure 17). These units were developed to meet requirements of companies were FleXicut has already been installed (such as Nýfiskur, Sandgerði and Vísir hf. Grindavík, Iceland). Furthermore, Information gathered within the project has also established a strong basis for future evolution of the fish industry.

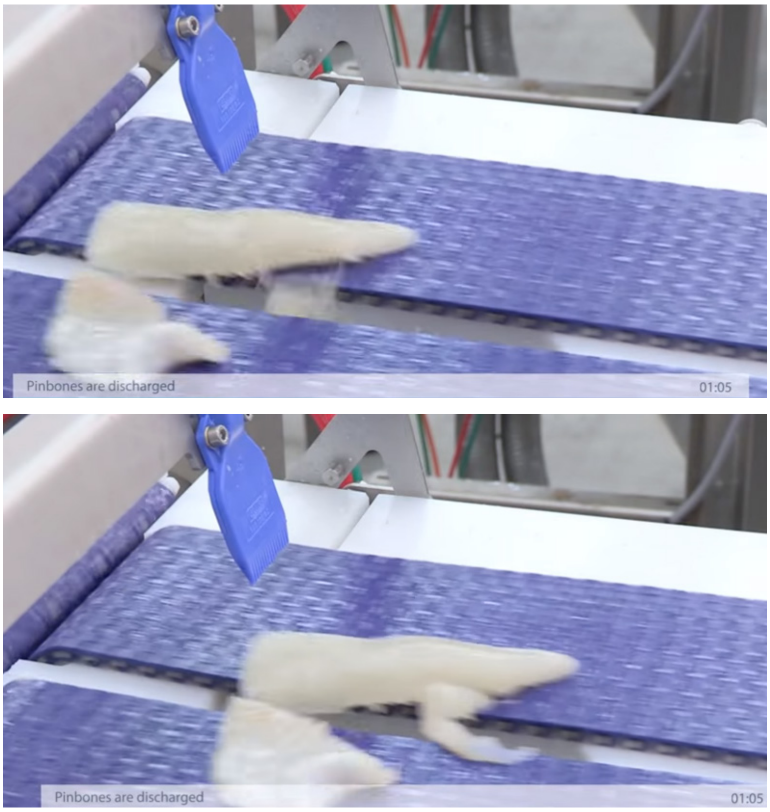

Figure 14. *The pinbones are removed automatically using high pressure air jets.*

Figure 15. *The FleXicut's twin blades knives can divide the loin, cut the belly flap or tail, or portion the fish to customer specifications. Each fillet can be cut differently depending on its size and weight. (https://www.youtube.com/watch?v=CCZQrrnitSI)*

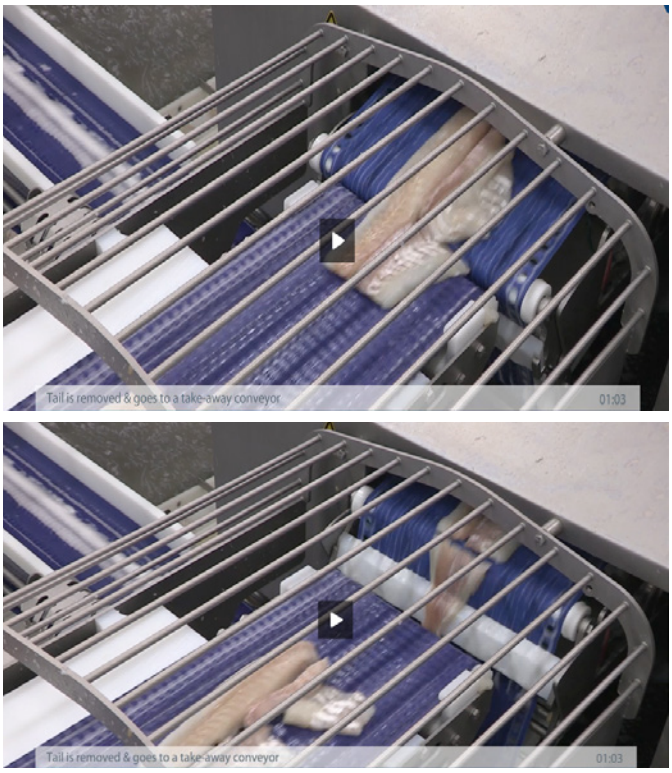

Figure 16. *Tail is removed and toes to a take-away conveyor belt*

Figure 17. *The FleXisort product distribution system allocates each of the various outputs to different packing lines or other process streams. (https://www.youtube.com/watch?v=CCZQrrnitSI)*

5. Economic benefits of FleXicut

The main benefits of FleXicut are summarised below:

Automatic pinbone removal	Cuts along the pin bone frame are based on precise position of pin bones in the fillet, determined after X-ray imaging.
Uniform cuts	Uniform cuts. Performance consistent, whereas efficiency of workers varies between person, time of day, between days, etc. Not depending on skills of employees, it can take up to 6 months to train a new person.
Optimization of portioning	Flexibility in cutting patterns. Optimization of portioning of fillets depending on fillet size. FleXicut calculates from X-ray images, the approximate size of fillets, and selects which cutting pattern to apply for each fillet size for optimization of product value. Production can continually be optimized with regard to order requirements.
Raw material variety	FleXicut can be used for different whitefish species and varying condition of raw material.
Traceability	Brings QC and individual monitoring to a new level. Fillets can be tracked from flowline throughout the process and into packing.
Quality	Less handling of the fillet, with other new units will lead to more continous flow of raw material and products which improves quality of fish.
Labour	Number of employees can be reduced since less time is needed at the trimming line.
Throughput	Meets industry demands on throughput (matches the throughput of one filleting machine

The economical benefits can depend on production volume and number of employees within each plant. The number of manual operatores is particularly important in larger plants (≥30 metric tons per day). Throughput, continous flow and consitent and standardized performance of processing and maintaining high quality and freshness of the fish through the productions are relevant for all producers. Effects of quality during processing is harder to evalute, partily because adverse effects on products, usually become visible when received by buyer/consumer. One example is temperature rises as fillet wait at buffering points (in traditional production) which will be minimized by FleXicut and related innovations. More standardised production and flexibility will strengthen market position of the Nordic Fish industry on global scale.

Whitefish industry

For a production plant processing 30 metric ton per day, gaining only 1% in yield of primary products, and reducing number of from 18 to 12 (33%) , would yield a total value of 34.436 EUR or 329.612 NOK per month (calculations shown on following page). Note, the gain yields may vary between processing plants, for example due to varying condition of raw material. Also, the rate of defects present in raw material and flaws due to processing affects the need for manual operators for pre-trimming.

Lower number of employees at the trimming line is not equal to jobs lost. On the contrary, it can create oppurtuntities for the industry to create more value at other stages in the process or utilise rest raw material in new ways.

Marel

For Marel, the innovations means 4-8 sales of FleXicut per year. Additionally, sale of related systems there are beeing developed, will deliver revenues.

Raw material (gutted with head)	**30**	**ton/day**
Pre-trimmed fillets without skin	47,5%	Processing yield

	Process before		Process after	
	Product value			
Loin	10 €		10 €	
Tail/baby fillet	4 €		4 €	
Block	3 €		3 €	
Mince/offcut	1 €		1 €	Gain in primary product yield per month
	Percentage of different products			
Loin	49,9%		50,7%	0,8%
Tail/baby fillet	25,9%		26,1%	0,2%
Block	14,6%		13,8%	
Mince/offcut	9,6%		9,4%	
Total	**100,0%**		**100,0%**	
	Capacity			
Average number of production days per month	21		21	
Working Hours	8		8	
	Labor cost			
Number of employees	18		12	
Average employee monthly costs	2.647,00 €		2.647,00 €	

Necessary flexicut theoretical throughput & belt speed

Average fillet weight	700	gr
Average fillet length	500	mm
Number of fillets per minute	**42,4**	fillet/min
Beltspeed	**424**	mm/s

Value generated per month	
Primary products	18.554 €
Employee costs	15.882 €
TOTAL	**34.436 €**

Production volume (gutted with head) 630 ton/month

Values for key parameters of FleXicut are as shown in table 2.

Table 2. Key parameters of the FleXicut and their limits of operation according specifications as defined at project start

Parameter	Realistic / Objective per line	Ideal / Ultimate per line	Performance reached in March 2015
Fish species	Cod, saithe	Cod, saithe, haddock	Cod, saithe, haddock, wolffish
Processing capacity, fillets/minute	30 fish/min 60 fillets/min	Up to 25 fishes/Min (3 kg fish gutted with head) Up to 50 fillets/min for 750 g fillets	The capacity in terms the number of fishes/min depends on fish size. The processing capacity of FleXicut meets the processing capacity of one filleting line.
Fillet dimensions, length x width	Max. 600 x 300 mm	Max. 800 x 300 mm	FleXicut can cope with up to 2.5 kg fillets (10 kg fish, gutted with head).
Fillet thickness	Max 15 mm	Max. 70 mm	
Gaping level	1 through 3	1 through 5	FleXicut can cope with raw material in different condition.
Min. pinbone length detected	10 mm	3 mm	FleXicut can detect and remove pinbones down to 0.1 mm in diameter and 14 mm length and 0.2 mm width and 7 mm length.
Min. pinbone diam. detected	0.5 mm	0,2 mm	
Yield in pinbone removal (of fillet weight)	10%	6%	The average pinbone removal is within the limit of the ideal objective of 6%
Number of manual trimmers	20	12	Within the processing plant, where the 0-serie has been installed the capacity of the trimming line has been increased by 40%.
Number of other line operators	6	6	

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Kristin Anna Thorarinsdottir and Kristjan Hallvardsson (eds.)

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Title :

Automated Pinbone Removal in Cod and Whitefish

Automated Pinbone Removal In Cod and Whitefish

Abstract:
The objective of this project was to develop an automated process system (FleXicut) for detection and removal of pinbones. FleXicut incorporates these two critical processing steps in one machine.

- High resolution X-ray technology is used to locate the bones with extremely high accuracy, down to 0.2 mm pinbones and software to guide water jets during cutting for pinbone removal. Previous work has revealed that low resolution sensors do not fulfill requirements regarding sensitivity in bone detection.
- The water-jets are very flexible, enabling the FleXicut to perform a variety of cutting patterns. The angle cutting option allows it to follow the curved lines of the bone frame very closely, thereby further reducing pinbone material.

FleXicut is also equipped with a built-in blade cutter, to optionally cut the tail piece. With the X-ray scanning and water-jet cutting performed on the same belt, there is no risk of movement between the bone detection and cutting processes, which ensures a superb level of cutting accuracy based on the bone location.

Automated pinbone removal has the potential to increase the sustainability, profits and market for cod and other wild whitefish species. The high precision in locating bones and guiding of bone removal leads to higher yield of raw material. Increased automation of the process results in reduced number of trimming operators needed and improved handling during processing. Thus, the outcome is added value and higher quality of products.

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Nordic Innovation
Stensberggata 25, NO-0170 Oslo, Norway
Phone: +47 – 47 61 44 00
info@nordicinnovation.org
www.nordicinnovation.org

Main contact person:
Kristjan Hallvardsson
Marel Iceland ehf
Austurhraun 9, IS-210 Gardabaer
Mobile: +354 – 8 25 81 21
Email: Kristjan.Hallvardsson@marel.com

APRICOT

Automated Pinbone Removal In COd and WhiTefish

The main deliverable of APRICOT is FleXicut, a system that incorporates two critical processing steps in one machine: precisely locating pinbones in whitefish fillets and then cutting the fillets to remove them.

The FleXicut uses the latest X-ray technology to locate pinbones with extremely high accuracy, down to 0.2 mm. Determining the orientation of the bones is critical in order to cut out less flesh and leave more on the loin.

The water-jets for the bone removal process are very flexible, enabling the FleXicut to perform a variety of cutting patterns. The angle cutting option allows it to follow the curved lines of the bone frame very closely.

With the X-ray scanning and water-jet cutting performed on the same belt, there is no risk of movement between the bone detection and cutting processes, which ensures a superb level of cutting accuracy based on the bone location.

For more information, contact a local Marel representative (marel.com).

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NORDIC INNOVATION, Stensberggata 25, NO-0170 Oslo // Phone (+47) 47 61 44 00 // Fax (+47) 22 56 55 65 // info@nordicinnovation.org