Awadh Internship Carnival

IIT Ropar

Highly Efficient Fish Deboning Machine

Team A

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ACKNOWLEDGEMENT

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We are grateful to **Dr Pushpendra P. Singh**, Associate Professor (Department of Physics), Indian Institute of Technology Ropar and all the esteemed members of the Carnival for providing facilities in successful completion of this work.

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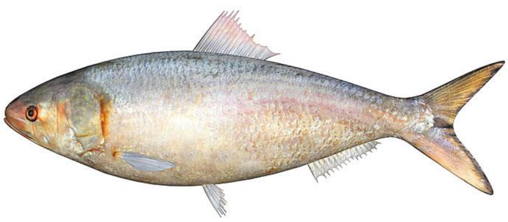
1. Problem Definition:

The project required us to design a highly efficient fish deboning machine with built in human machine interface and IoT features. The machine should cater to the species listed in Table 1 and should provide option to choose between fish fillet and fish mush as the end product.

Rohu	
Catla	
Mrigal	
Tor Tor	
Hilsa	

Pulasa	
Kajuli	
Tilapia	
Rani	

Table 1: Fish species compatible with the machine

Some other requirements comprised of: -

1.1 The machine should be fully automated and should not require human intervention during any stage of the process.
1.2 The machine should house IoT features for improving the usage of the machine.
1.3 The machine should increase the efficiency of fish processing and should also solve some inherent problems face by the people in the present scenario.

Since fish processing was a process that none of the team members were fully aware of; hence the team conducted an extended research on the fish biology, present assembly line technologies utilized for the processing of fish of various types and also the issue which were yet a challenge for the processing industry.

2. Engineering Challenges

Based on our research the team was able to identify the problems from the biological side pertaining to the structure of the fish. Fig 1 shows the structure of the fish and a visual representation of all the different types of bones present in a fish.

Fig 1: Generic bone structure of a Fish

As clearly visible from Fig 1, the body of the fish houses several different types of bones varying in shape, size and thickness. The head and tail bones are to be removed during the head and tail removal process with the central bone or spine of the fish removed during the filleting process. The two main challenges here are the removal of the thin bones surrounding the spine of the fish as well as the bones in the fins of the fish. The bones surrounding the spine (Y-bones) of the fish are very thin generally with a thickness of less than 1mm. The small thickness of the Y-bones prohibits the use of cutter or excessive force mechanisms to remove them from the meat of the fish. Also, the bones present in the fins of the fish comprise of two different set of bones, thicker ones on the inside of the body and light and slender bones on the outside of the fish body. Hence a rooted removal of the fins of the fish is also essential.

3. Present Technologies

Before moving forward, it was important to have a look at the current technologies being employed in the industry for carrying out the processes.

3.1 Fin Removal Mechanism

The current method utilized in the industry often involve see intervention of human to carry out the fin removal process. The fins are generally removed using knives or scissors (as shown in Fig 2) before further processing of the fish.

Fig 2: Removal of fins from fishes

3.2 Descaling Mechanism

The current method makes use of scrapping tools and rollers for the descaling of the fish. The descaling of the fish involves scrapping of the scales from the outer skin of the fish (ref Fig 3). These scales often house bacteria and dirt from the cultivation pond and hence it is essential to get rid of these scales during the processing of fishes.

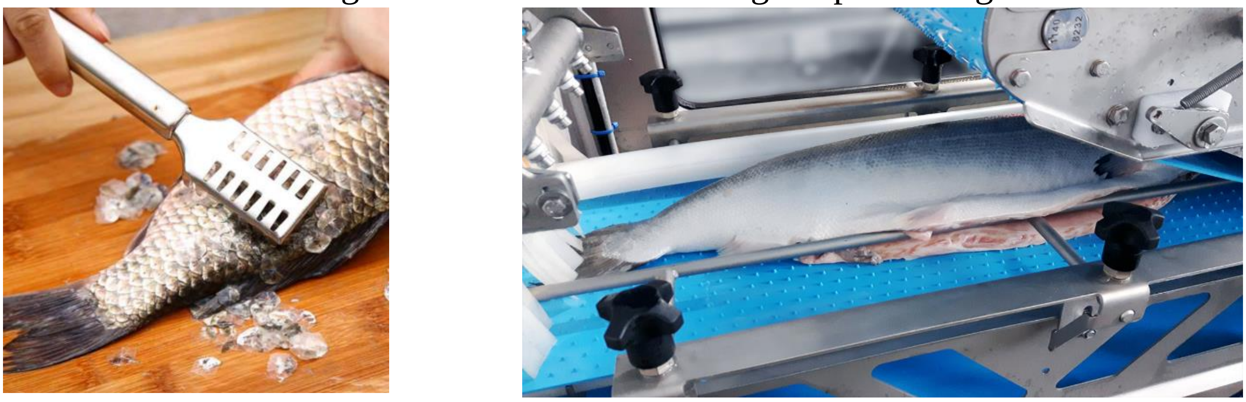


Fig 3: Descaling methods utilized in the industry

3.3 Head and Tail Removal

For the removal of head and tail of the fish, a high accuracy is required to preserve the most amount of meat for further processing. Hence the methods currently being employed in the large-scale fish processing plants involve fixing of the fish carcass into a pre made slot before the removal process. This task is generally done by a human operator who is tasked with fixing the fishes in the slots before the removal process.

Fig 4: A worker inserting the fish carcass in a slot for head removal process

3.4Deboning Mechanisms

Deboning process is aimed to remove the majority of bones from the fish and in the process obtaining the fish meat in minced format for consumption. Due to the presence of extremely small Y-bones, the efficiency of this process with the current processes is extremely low and the biggest concern for the processing industry. The current solutions available commercially comprise of majorly two types of mechanism. The first method involves the use of belts and perforated cylinder to extract out the meat from the fish (Fig 5).


Fig 5: Example of commercially available deboning machine

The other mechanisms utilized the make use of a similar arrangement as seen as in the bones crushing of chicken and other sources of the meet. The mechanism contracts the mixture of the meat and then forces the meat out of a perforated surface to obtain the meat leaving behind the bones in the machine itself. This method has a slightly lower efficiency when compared to the belt and perforated cylinder mechanism as it is aimed for carcass having bigger bone size.

Fig 6: Deboning Mechanisms utilized commercially

Since all of the methods demonstrated above have some room for improvement and also often involve human intervention hence it was a challenge for the team to remove the human component from the machine and make the process autonomous.

4. Process Layout

The flowchart in Fig 7 displays the process chart utilized in the fish processing machine proposed by the team. The processes are laid down in the order which they will occur in the machine.

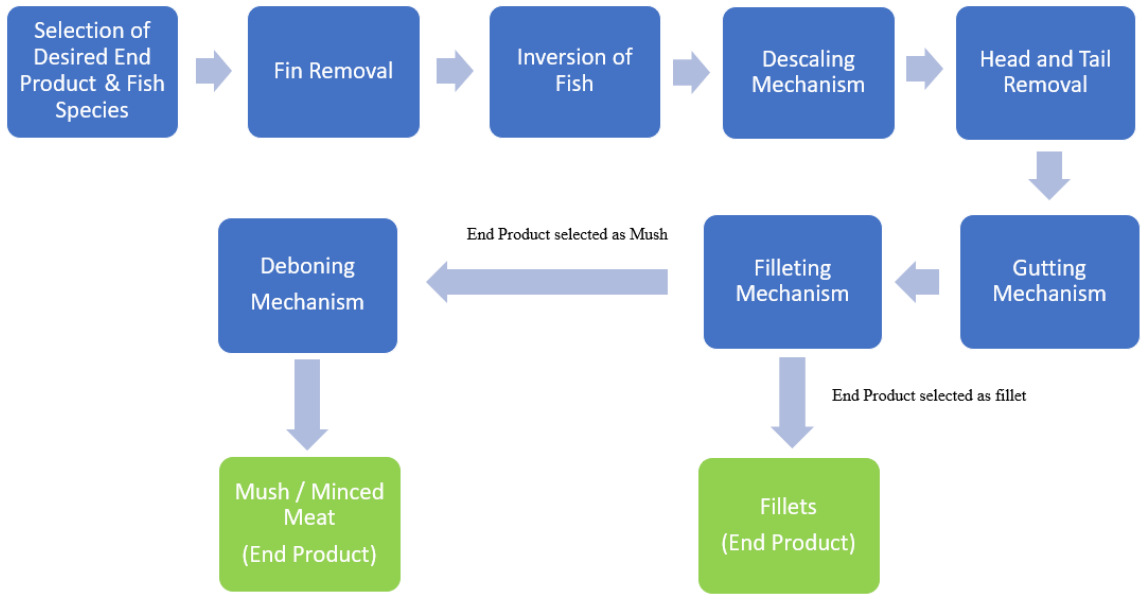


Fig 7: Process Flowchart

5. Mechanisms and their working

The first step in the machine involves the user to select the species of fish from the command module and also the type of end product i.e., fish fillets or mush (minced meat) as output from the machine. Once this step has been completed the fish enters the machine tail side first. The first mechanism that is located is the fin removal mechanism.

5.1 Weight and Length Measurement of the fish

When the fish enters the fin removal mechanism, an IR sensor mounted on top of the fin removal mechanism reads the weight of the fish and the conveyer belt is attached to weighing scale to measure the weight of the fish. The rise time from the IR sensor and correlating it to the speed of the conveyer we are able to determine the length of the fish for the tail head removal process.

5.2 Fin Removal Mechanism

The fin removal mechanism involves the combination of cutter and blades for the removal of fins from the fish body.

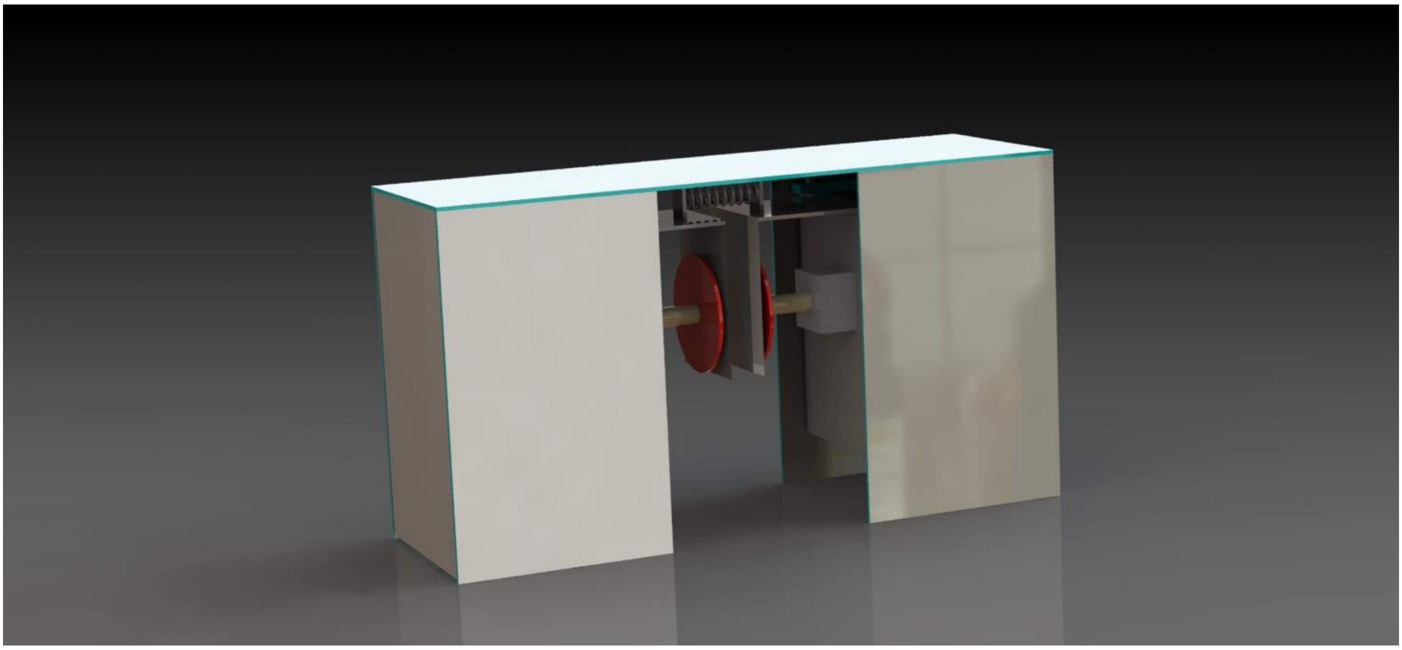


Fig 8: Fin Removal mechanism

The fin removal mechanism house tow blades on each side with a spring holding the two blades together. The use of spring is done to ensure that the blade always remains in tight contact with the body of the fish. Due to the streamline nature of a fish, the fins of the fish are located very close to the body and are prone to sticking to the body of the fish. When the fish is sent into the fin removal mechanism tail first, the spring mechanism ensures that the fins are separated from the body and protrude outwards of the blade surface. The red cutter as shown in Fig 8 cut away the fins from the fish carcass and the conveyer belt carries the fish forward.

5.3 Fish Inversion Mechanism

After successful removal of the fins the fish carcass is sent into the fish inversion mechanism to invert the direction head first for the further processes. The initial inclined wall is to make the fish land on the right side longer flap sideways with the head towards the left flap. A touch sensor ensures that when the complete fish is laterally on the flap. The left flap moves clockwise and at the same time the actuator moves upwards ensures that fish is turned headfirst.

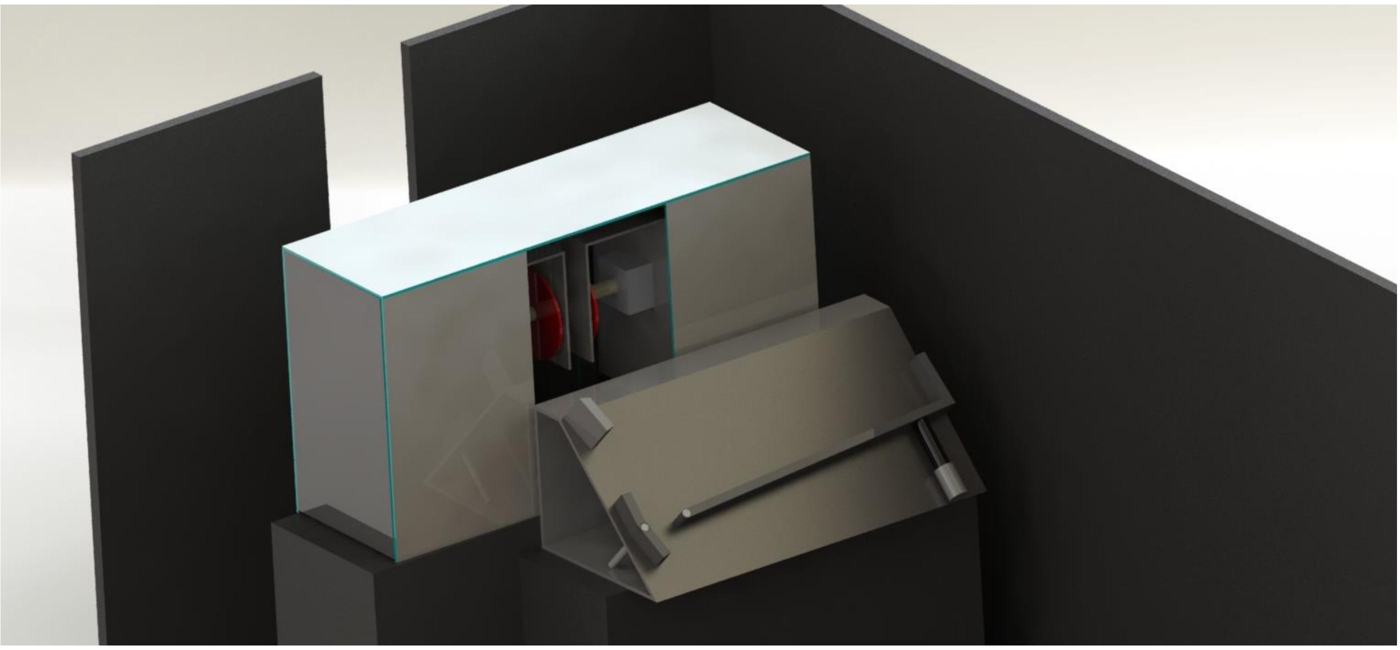


Fig 9: Fish Inversion mechanism

5.4 Descaling Mechanism

The descaling mechanism consists of two rollers and pressure plate. The mechanism utilizes two rollers so as to ensure the removal of the scales from both sides of the fish.

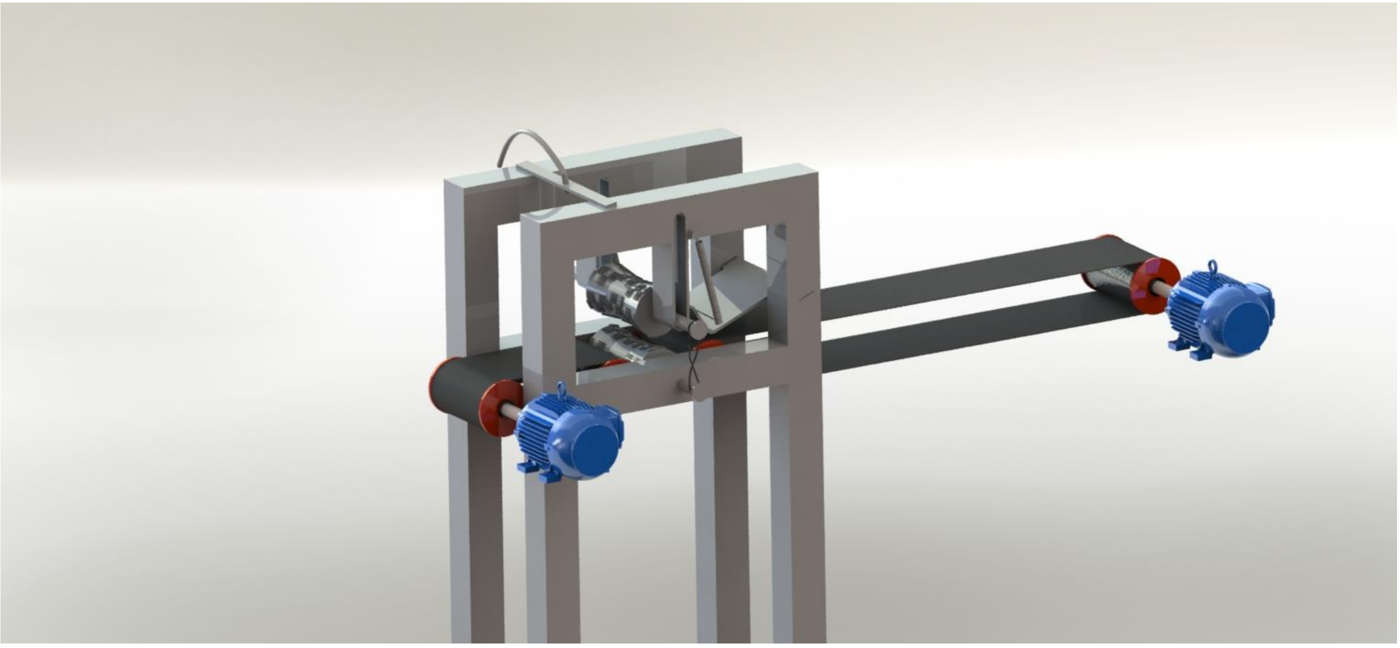


Fig 10: Descaling Mechanism

The pressure plate (attached with the spring) in Fig 10 ensure that the fish does not move through the mechanism swiftly hence providing optimum time for the rollers to remove maximum scales. The roller also consists of bristles of varied sizes to ensure removal of both large and small scales pertaining to list of variety of fish species processed by the machine. The rollers are connected through a cross-belt drive. The flexible nature of the belt ensures that the roller can move with respect to each other to ensure accommodation of varied thickness of fishes being processed in the machine.

5.5Gutting Mechanism

After the descaling mechanism, the fish using a combination of belts, is put down on its belly to undertake the gut removal process of the fish. The fish while being kept on its belly is transferred through the chamber of the filleting mechanism and then is passed over a cutter which incises a cut on the belly of the fish. After the cut is being made a waterjet mechanism rushes water inside the body of the fish through the incision and hence the guts through a combination of gravity and water jet, fall down and the fish carcass moves forwards for the filleting process.

5.6 Filleting Mechanism

Filleting of fish is done to remove carcass and fillets from fish. Before coming to filleting section, the fish is pre-processed i.e., descaling, head tail cutting and fin removal. Both Gutted and non - gutted fish can be filleted with this mechanism.

In this mechanism the important parts are- Fish Orientor, Transport belt, Gutting, back trim and cutter.

- Cutter Design

  Cutter is the main and important part of the filleting machine. It is a disc blade, there are two-disc blades positions at certain distance equal or approx. to the backbone thickness of fish so that when the fish passes through it the carcass get separated and two fillets came as a output.

- Calculations

  Power consumption of slicing, $P = \frac{2\times\pi\times N\times T}{60} = \frac{2\times\pi\times 1200\times T}{60}$

  Where, N = Rotational speed of blade

  The torque transmitted by shaft during slicing, $T = \frac{P\times 60}{2\times\pi\times N} = \frac{456\times 60}{2\times\pi\times 1200}$

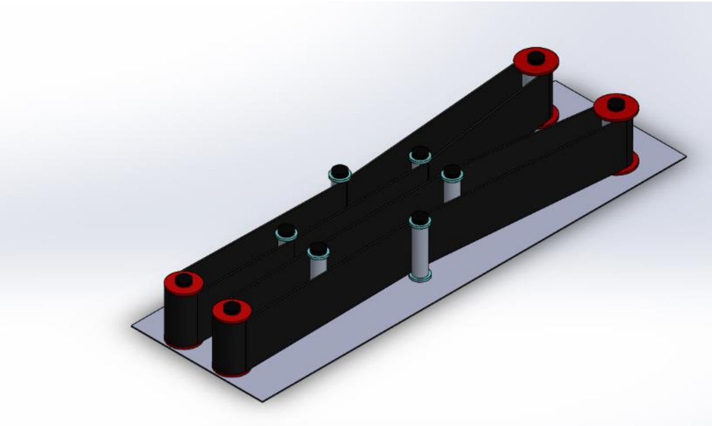
  Radius of the blade, r = 0.15 m

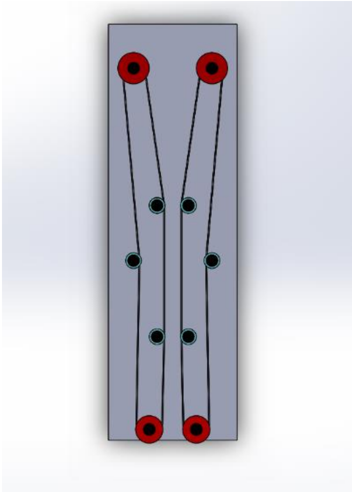
  The maximum slicing force of fish, F= T/r= 3.44/0.15=25N

- Design of belt roller arrangement (transport belts)

  Belt and rollers are arranged in the sides to transfer the fish. The belt speed is 30 m/min and the driving roller (which is attached with the motor) is of diameter 50 mm and the idlers of diameter 30mm. The total belt length is 200 cm and the thickness is 11 cm by considering the average thickness of fishes to have a firm grip on fish.

The main purpose for this arrangement is to make the fish moving in vertical orientation (held on its belly) and with appropriate velocity to make the process effective. The belt chosen is the standard belt manufactured by company specially for food processing.

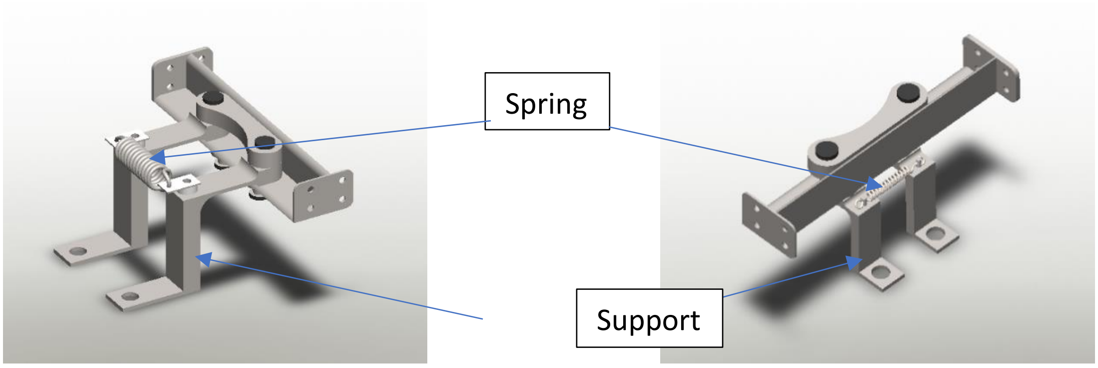


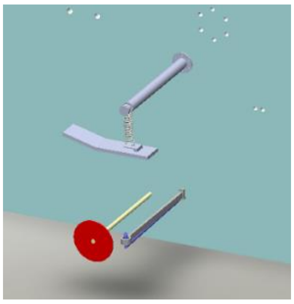


- **Arrangements for making the machine Universal (Multispecies Fishes)**

The return idler which is located at the starting of the machine where the fish enters it is held with a special arrangement through fishes with varying thickness can be transferred. The arrangement adjust itself by the size of fish.

The Cad model shown below shows how two supports on two rollers can move (rotatory motion) with spring attached to put back the rollers at default position.

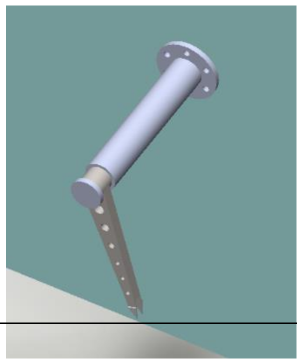




- Gutting

A simple saw is present to cut the fish. A water jet is Present to make sure the gut falls down.

Universal holder with incline (to ensure larger fish do not get stuck) is present to make sure that the fish does not displace due to the

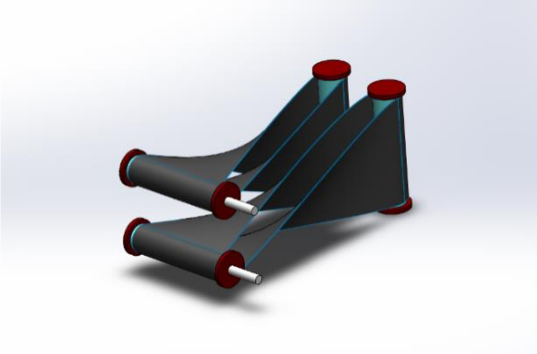


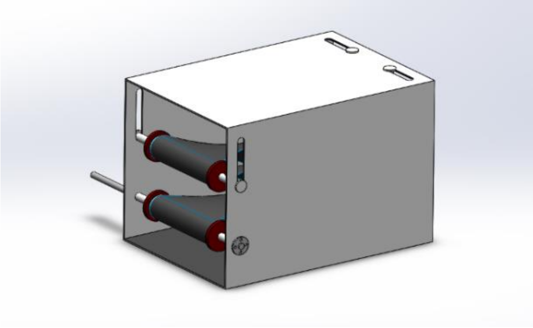
- Back Trim

Fish before transferring to the main disc blade cutter the back trim is made which make the filleting smoother and more perfect.

- **Fish Orientation Arrangement**

Fish is lying horizontally on conveyor before coming for filleting. So, to make it orient vertical or on its belly following arrangement is made with the help of roller belt.





Final Assembly

Fish on passing through orientor gets correctly oriented and then the support adjusted as per the size of width and then the transport belt keep fish moving and properly oriented. Gutting takes place and guts are removed then the back trim was made after which it passes through the main filleting cutter and the two fillets comes out and the carcass removed from bottom of the cutter.

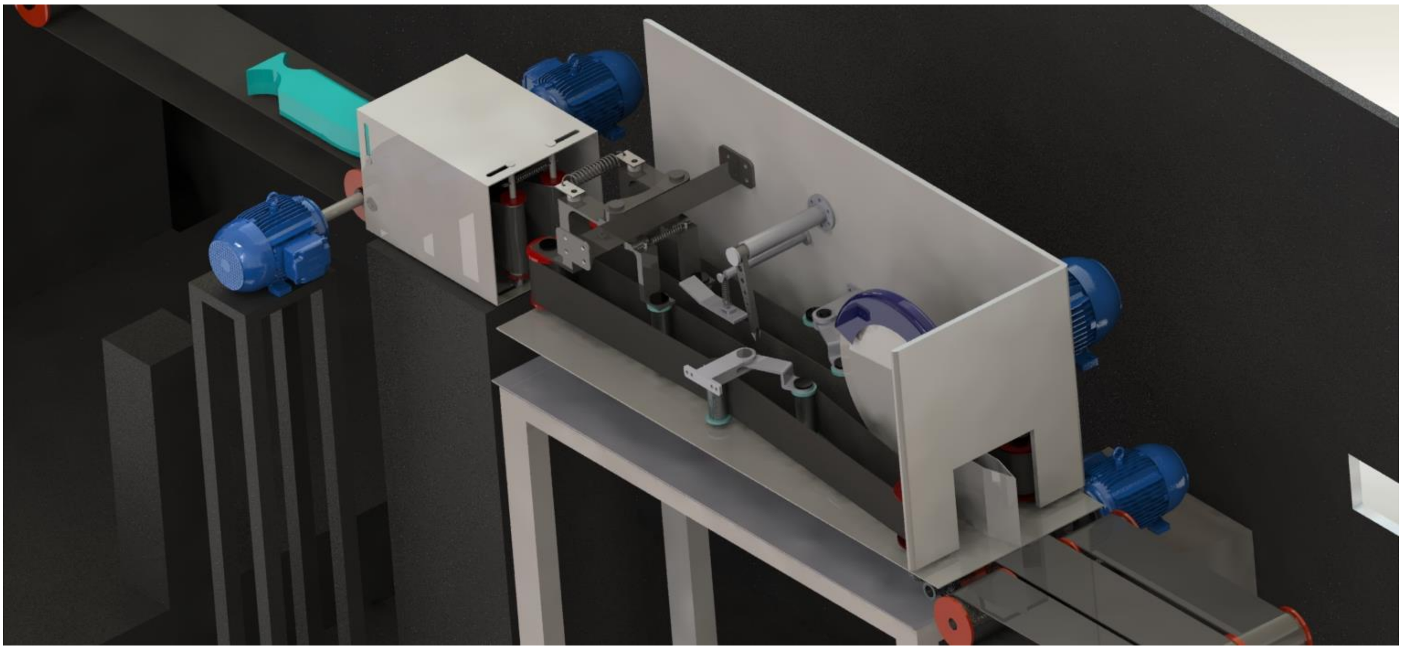


Fig 11: Descaling Mechanism

5.7 Deboning Mechanism

Based on the user selection at the start of the process, the machine only produces the minced meat when the ‘fish mush’ option is selected. If the user chooses the fish fillet option, then the flapper pushes the fish fillet outside the machine and the deboning machine remains disabled. When the fish mush option is selected the fish fillet obtained from the filleting mechanism are dropped into a shredder as seen in Fig 12.

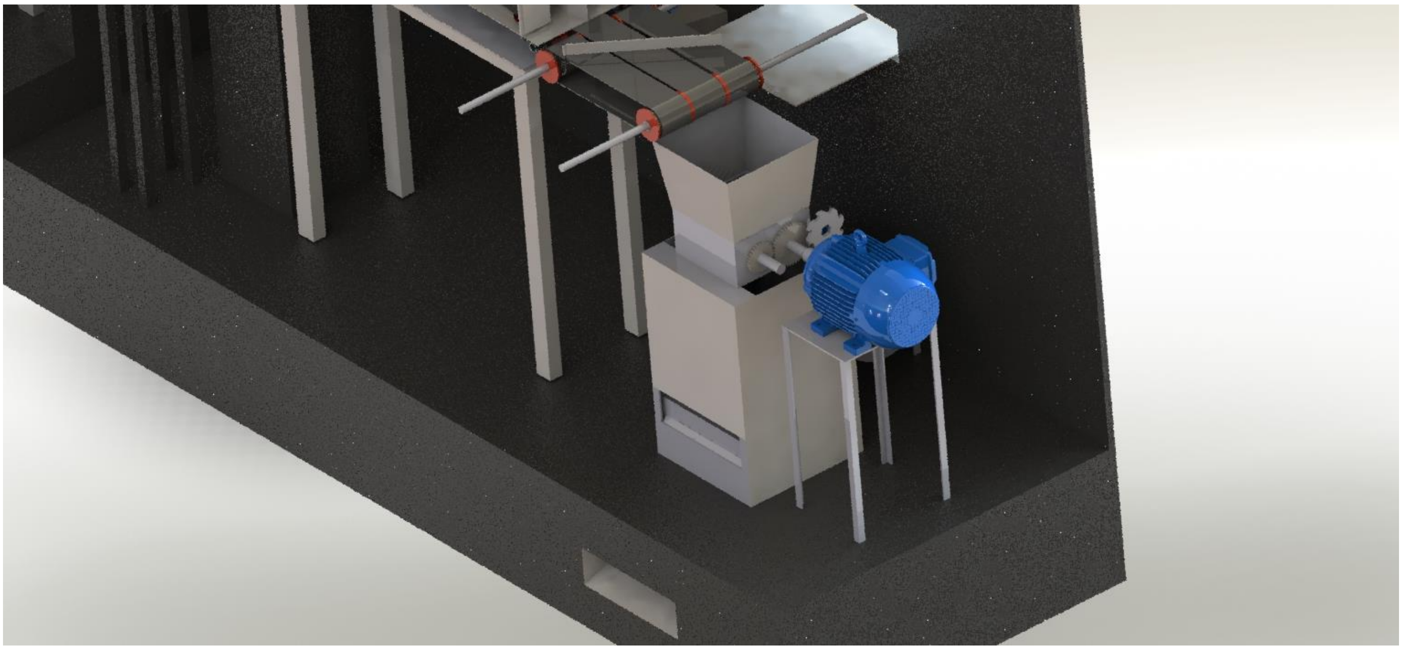


Fig 12: Deboning Assembly

The fish fillet which still consist of the Y-bones highlighted earlier is passed through the shredder to ensure the crushing of the fillet meat. This causes the fillet to lose its structural integrity and hence makes it easier to dislodge the meat from the bones. After the shredder, the meat is dropped on a grater plate where an angled meat pusher subjects the meat to friction and shredding through a grating plate which consists of 5mm holes. The 5mm hole size is chosen to ensure the best texture of the meat after the deboning process. The angled meat pusher ensures that the meat entire meat from the shredder is subjected to the grating process and the leftover bones from the meat are pushed and dropped out of the machine.

6. Control system and Electronics

6.1 Simscape Electrical : Model and Results

The entire electrical circuitry of the deboning machine is implemented in Simscape Electrical. The machine will work on single phase AC input of 230 Volts at 50 Hz Frequency.

Sub Models in the system:

➢ <u>AC to DC Converter Circuit</u>: A convertor circuit is implemented to convert the 230(sin50t) input to constant 230V dc output to be given to the motors.

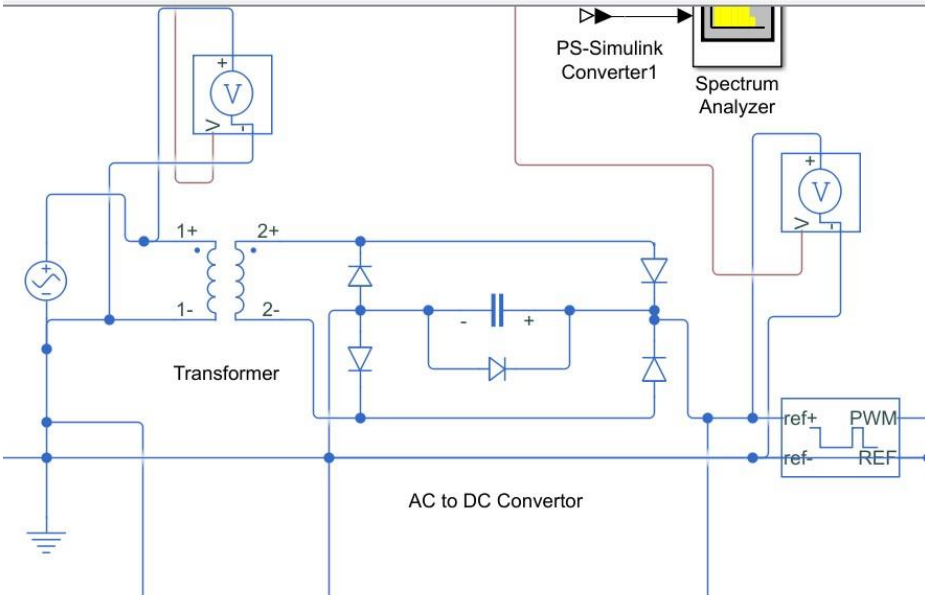


Figure 13: Convertor Circuit

The bridge rectifier, in this case a full-wave rectifier. It is made out of individual discrete diodes 1N4007 with forward voltage of 1.1V. The idea is that we switch the negative AC pulses to positive pulses, and leave the already positive pulses there. There is some voltage loss due to the voltage requirements of the diodes, but it is minimal. The end result is a pulsed DC voltage, going from 0 to maximum voltage at 50Hz. We use a capacitor of 47uF across the '+' and '-' terminals to smooth out the ripples. As the voltage rises from 0 to max, the capacitor charges. When the voltage starts to drop, the capacitor discharges through the circuit but at a much slower rate, in effect holding the voltage up while the supply drops to 0 and then rises again. Once the voltage rises to where the capacitor voltage is, it recharges the capacitor and surges back to max again. As long as the ripple doesn't get below a certain value. We can use that to power a voltage regulator, which simply stabilizes the wobbly input voltage to a specific output voltage. Full-wave rectifiers are better here than half-wave, since there is less time between the high and low pulses, resulting in a more stable output. Here we are getting a constant +230V dc output after the rectification.

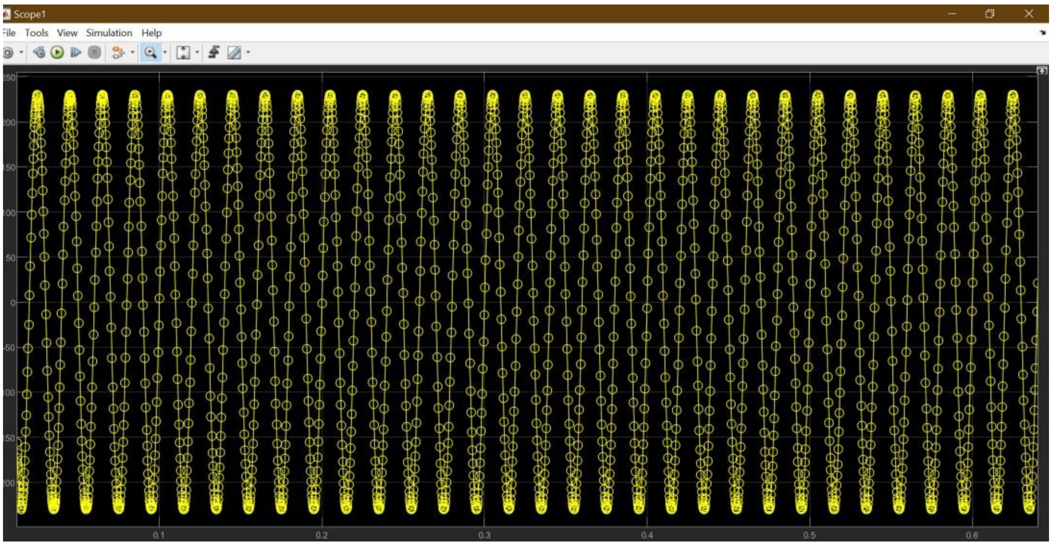


Figure 14: 230V, 50Hz AC Supply

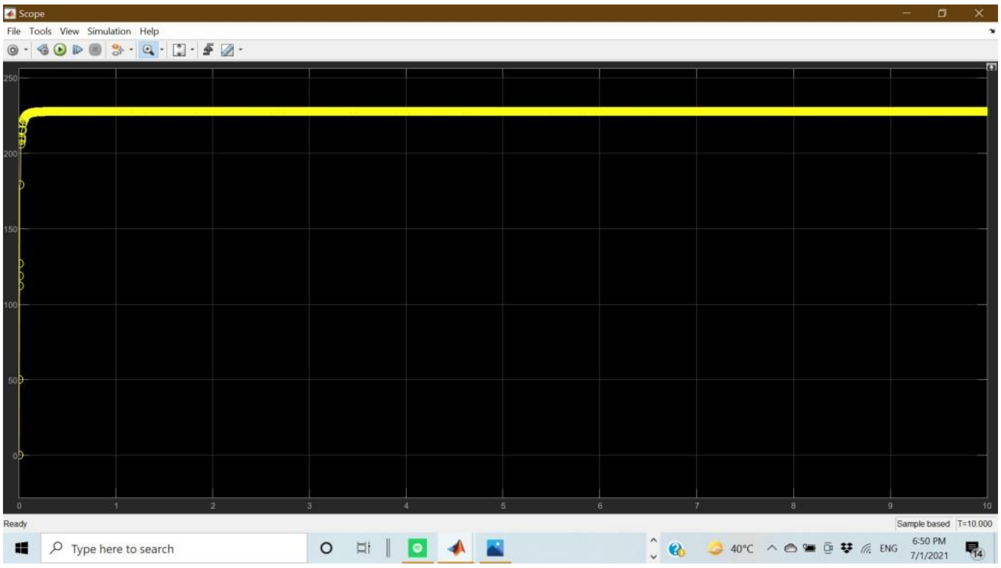


Figure 15: +230 V DC output

- Controlled PWM Voltage and H Bridge: The DC Voltage output is fed into a PWM controller with a switching frequency of 1000Hz of successive pulse. The output of the PWM controller is set at 5V which is to be fed to the H Bridge Industrial Motor controller rated at 5V DC input.

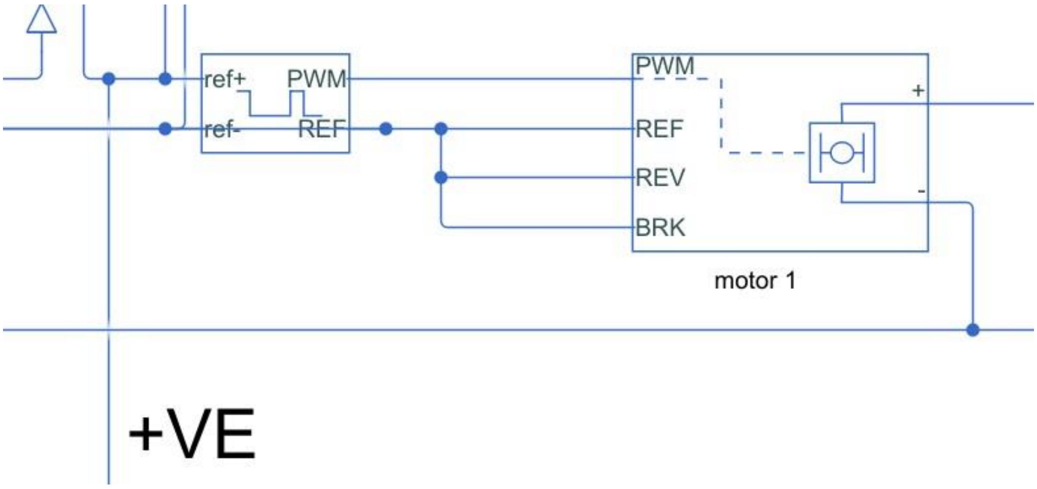


Figure 16: PWM and H Bridge

- Industrial Motors: For the purpose of Fin Removal, Descaling, Head& tail removal, Head collection, Filleting, Gutting, and to run Conveyor belts we have used industrial motors rated at 100W , 100 V , 5N-m Torque. The voltage output from the H bridge is amplified to 100 V to run these motors.

- Fin Removal: Two motors are used for Fin removal purposes. The current characteristics of these motors are plotted in the graphs. For Fin removal the motors use 1.0078 Amps of Current in its operation. Total power consumed = (2*100*1.0078) = 208 W

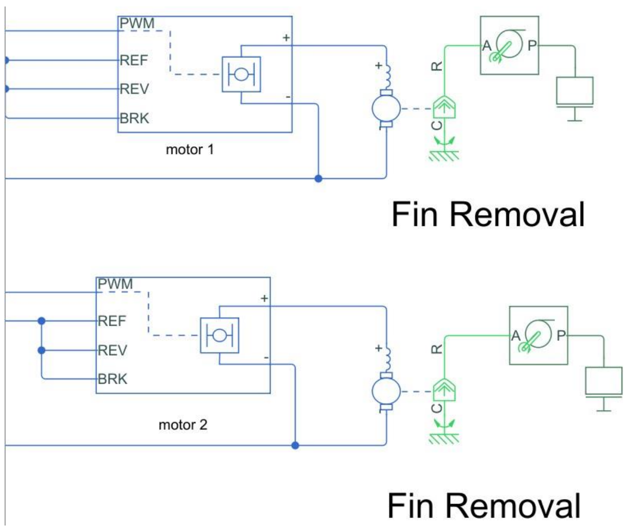


Figure 17: 2 Motors for Fin removal

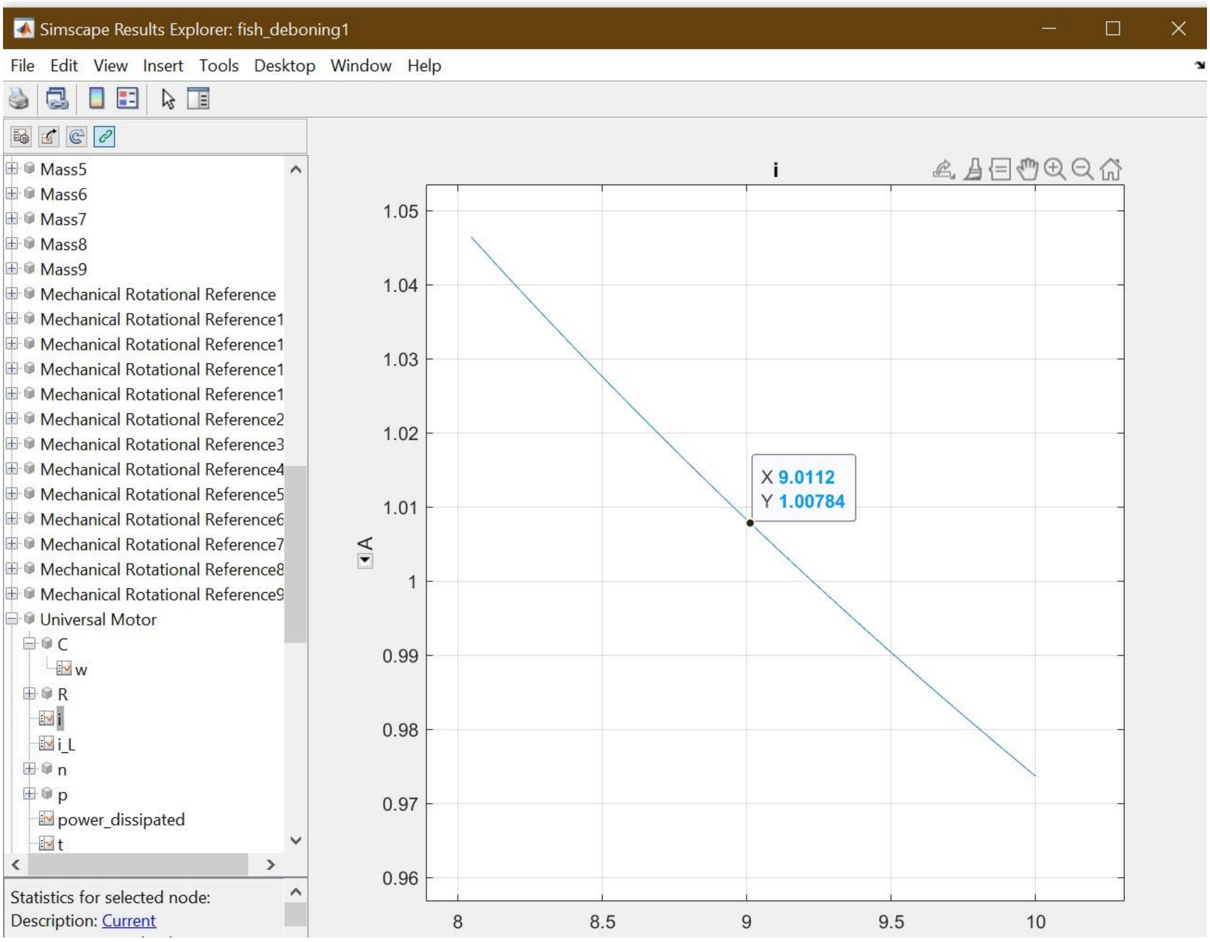


Figure 18: Current Characteristics of Motor

- <u>Descaling & Head, Tail Removal</u> : 1 motor each is used for these two purposes The current characteristics of these motors are plotted in the graphs. For these the motors
  use 1.0078 Amps of Current in its operation. Total power consumed =

  (2*100*1.0078) = 208 W

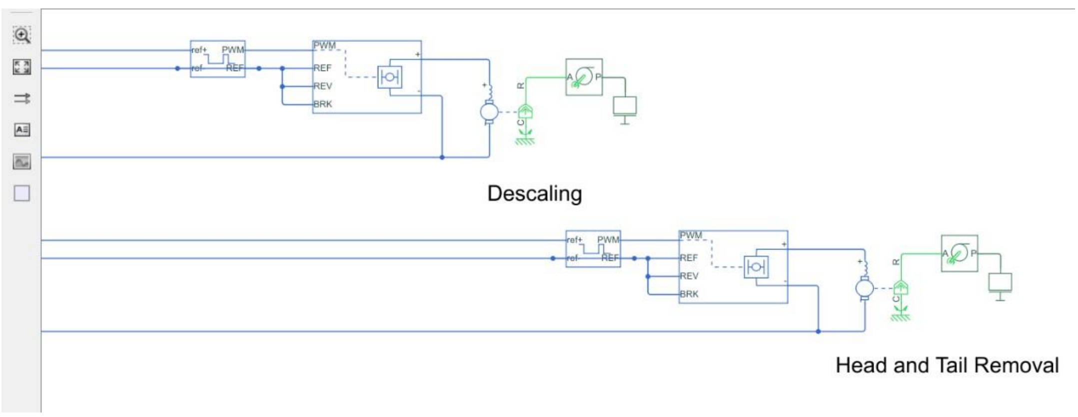


Figure 19: Descaling and Head, tail removal

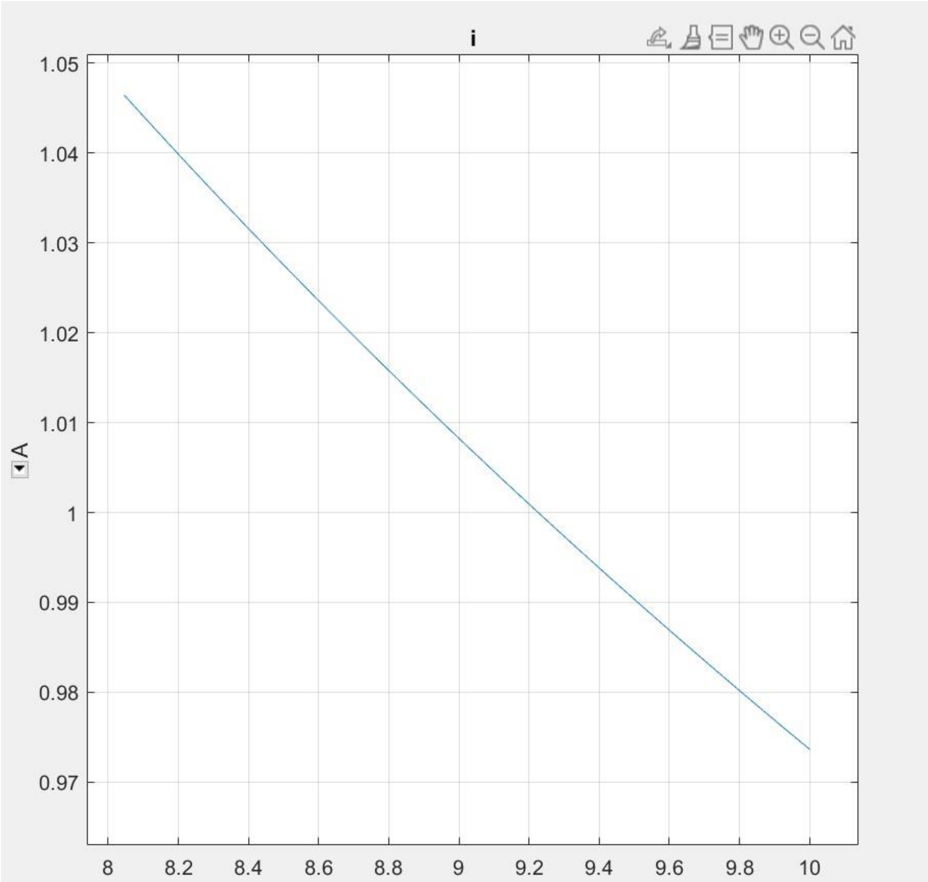


Figure 20: Current characteristics

- <u>Head Collection:</u> Fish head is also consumed; this motor acts as a flipper to collect the severed head of the fish and store them in a separate container. For this the motor use 1.04 Amps of Current in its operation. Total power consumed = (100*1.04) = 104W

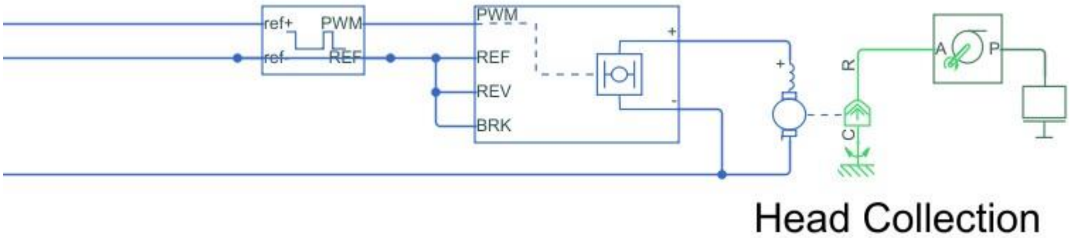


Figure 21: Head collection

- Gutting: The fish is Gut to separate the organs for this the motor use 1.04 Amps of Current in its operation. Total power consumed = (100*1.04) = 104W

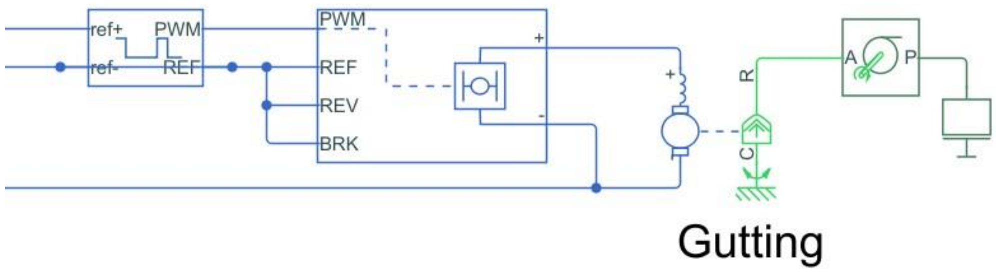


Figure 22: Gutting

- Filleting: The fish is filleted during this process according to the used demands. For this the motor use 1.04 Amps of Current in its operation. Total power consumed = (2*100*1.04) = 208W

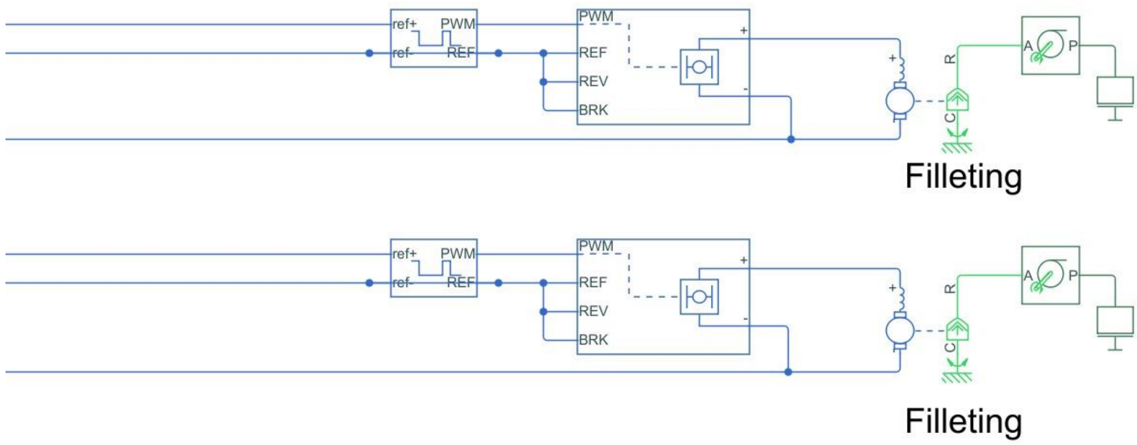


Figure 23: Filleting

- Option for Filleting/Deboning: During this process the motor separates the fillets obtained on the basis of the input of the user to the human machine interface i.e. whether they want a fillet or deboned mush. For this the motor use

0.90 Amps of Current in its operation. Total power consumed = (100*0.90) = 90W

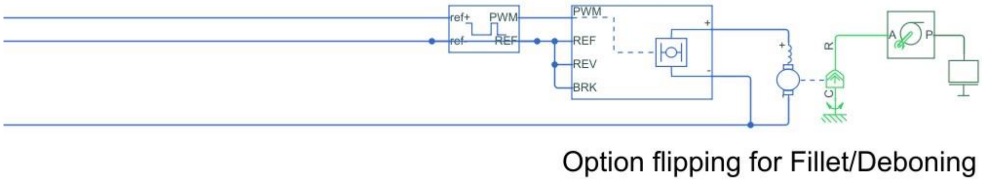


Figure 24: Fillet/Deboning

- Deboning: This motor runs the perforated drum for deboning this motor is rated at 230V. . For this the motor use 0.25 Amps of Current in its operation. Total power consumed = (230*0.25) = 57.5W

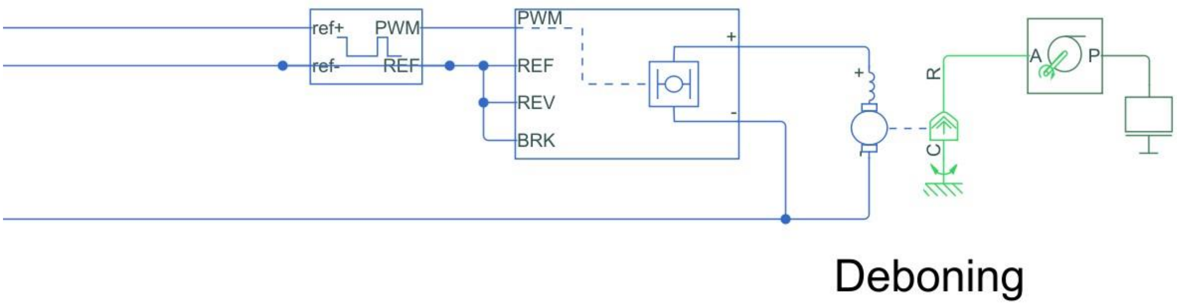


Figure 25: Deboning

- Motors for running Conveyor belts: In total 3 motors are required for running the conveyor belt at 60 Rpm. For this the motor use 1.04 Amps of Current in its operation. Total power consumed = (3*100*1.04) = 312W

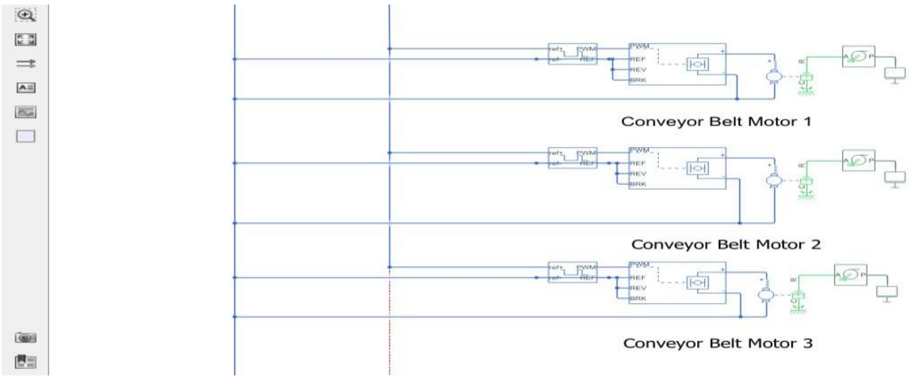


Figure 26: Conveyor motors

Total power consumed by all motors: 1293 Watts

Power rating of Machine: 1293-Watt hour

1. Simulink: Control System for Speed control of Motor

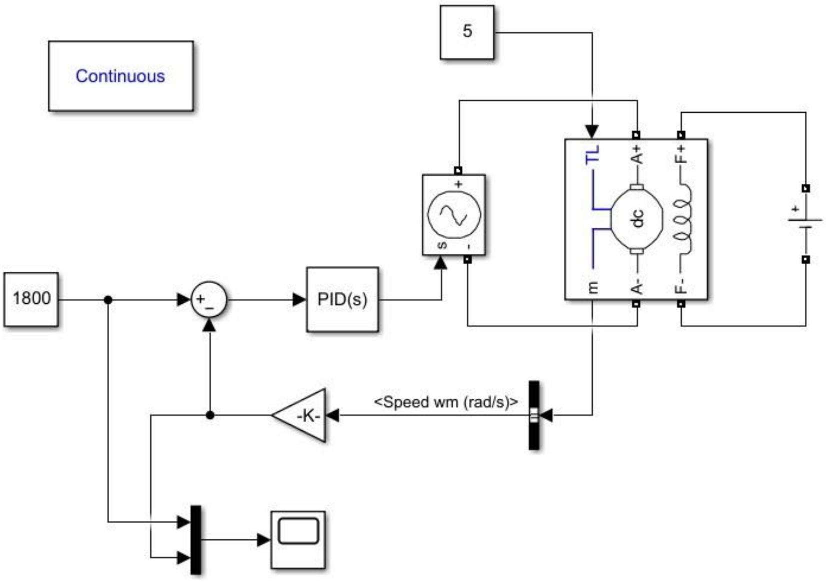


Figure 27: Control System

A closed loop PID based control system is designed for the optimal speed control of the Motor. The constant is set at 1800 Rpm which is required for the deboning process. Here the Dc machine is fed with variable voltage supply its RPM output is obtained and is multiped by specific gain constant to convert it to RPM. This acts as a feedback signal to the control system this is subtracted from the constant RPM, we want i.e., 1800 RPM which produces the error signal, this error signal is fed to PID block where the gains Kp, Kd, Ki are tuned accordingly to reduce the settling time (Ts) and minimize the maximum overshoot (Mp). The actuating signal obtained produced is given to the variable voltage supply. The results are plotted using a scope.

Kp = 0.851320759653448

Ki = 11.6736558254255

Kd = 0.014231201926504

The stable control system parameters obtained:

Rise Time = 0.0615 secs

Settling Time = 0.201 secs

Overshoot = 6.8%

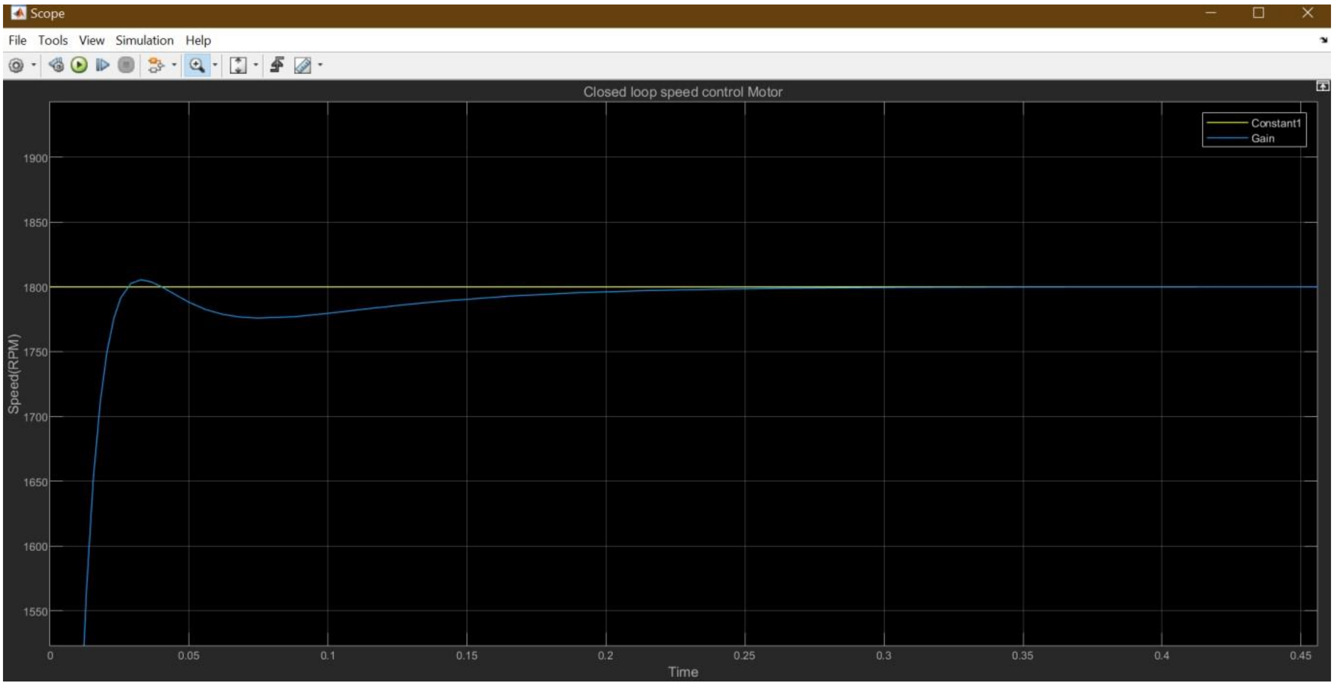


Figure 28: Control system response

6.2 MATLAB: Controller Verification

A live script is written in MATLAB with certain motor constants , through this we calculated the continuous time transfer function of the motor

```
J     = 0.01; b = 0.1;
K     = 0.01;
R = 1; L = 0.5;
s = tf('s');
P_motor = K/((J*s+b)*(L*s+R)+K^2)
```

P_motor =

0.01

0.005 s^2 + 0.06 s + 0.1001
Continuous-time transfer function.

Now a PID Controller is added to the system and its output was obtained

```
Kp = 100;
Ki = 200;
Kd = 10; C = pid(Kp,Ki,Kd); sys_cl =
feedback(C*P_motor,1); step(sys_cl, 0:0.01:4) grid
title('PID Control')
```

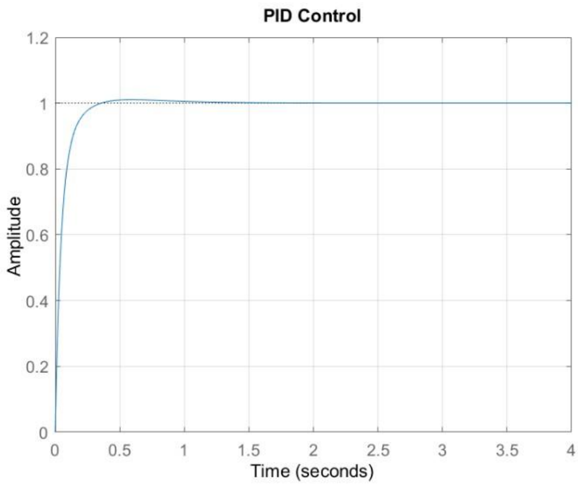


Figure 29: PID plot

Root Locus of the open loop transfer function is obtained for learning about absolute stability of the system.

```
%Root Locus%
 controlSystemDesigner('rlocus', P_motor)
```

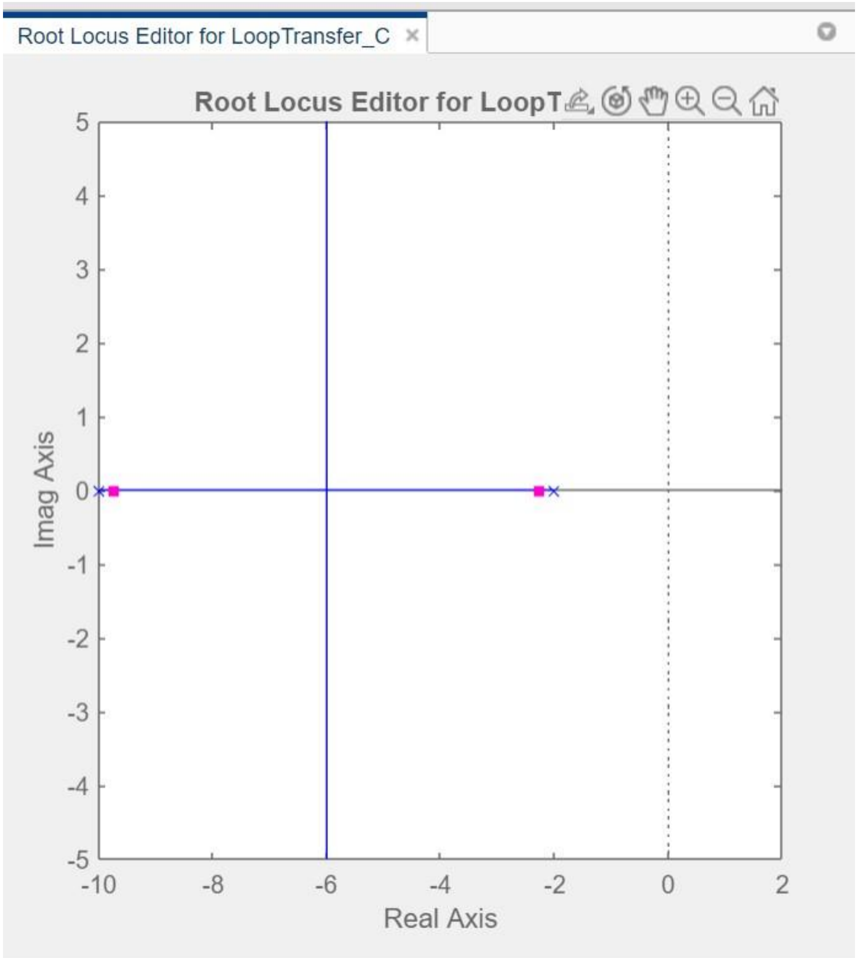


Figure 30: Root Locus

Since the Root locus is towards the left of the imaginary axis hence the system is stable.

Bode Plot is also obtained for the system for information regarding relative stability of the system. The gain margin and phase margins are also calculated

```
bode(P_motor) grid
title('Bode Plot of the Original Plant')
```

```
margin(P_motor)
[Gm,Pm,Wcg,Wcp] = margin(P_motor)
```

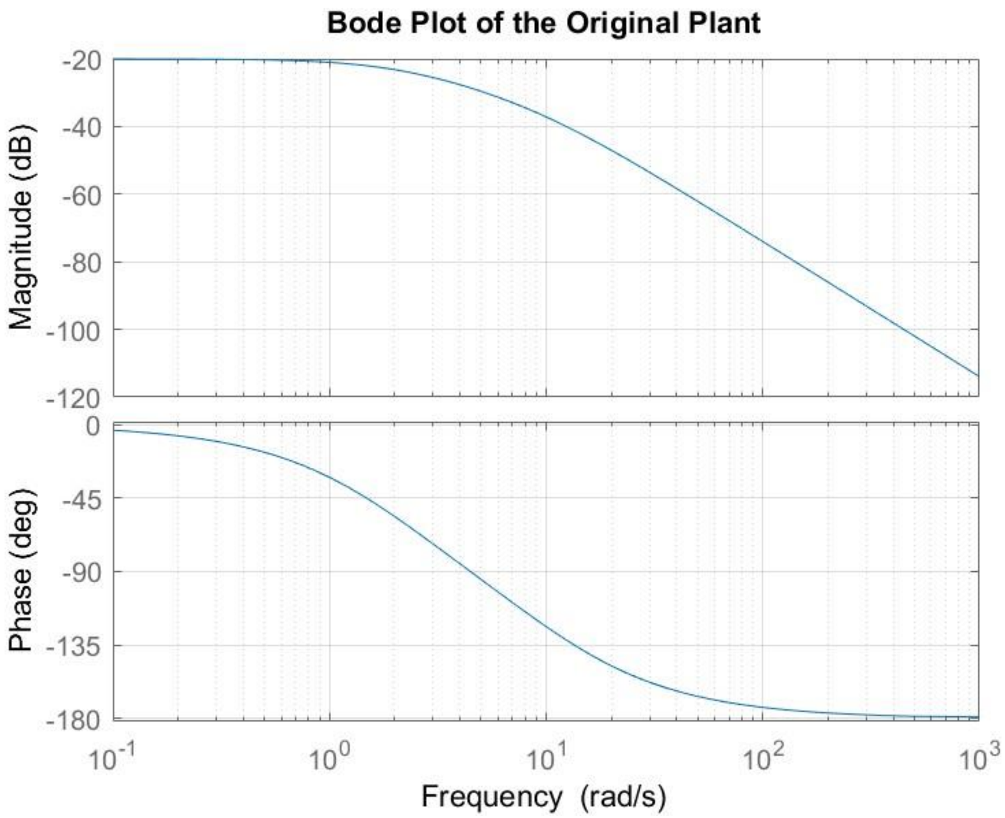


Figure 31: Bode Plot

Gain and Phase margins:

Gm = Inf
Pm = Inf
Wcg = Inf
Wcp = NaN

Since there are coming out to be Infinity so our motor will always be stable throughout its functioning in the machine.

6.3 Fritzing & C++: IoT Circuit and Program

The amount of fish weight obtained is sensed thorough a load cell controlled by an

ESP8266 WIFI Module, this module will send the real time weight data to MATLAB ThingSpeak an online IoT analytics platform, The farmers can know about the amount of fish meat produced and compare their produce. It will also have a temperature sensor LM35 to keep track of the temp of fish obtained.

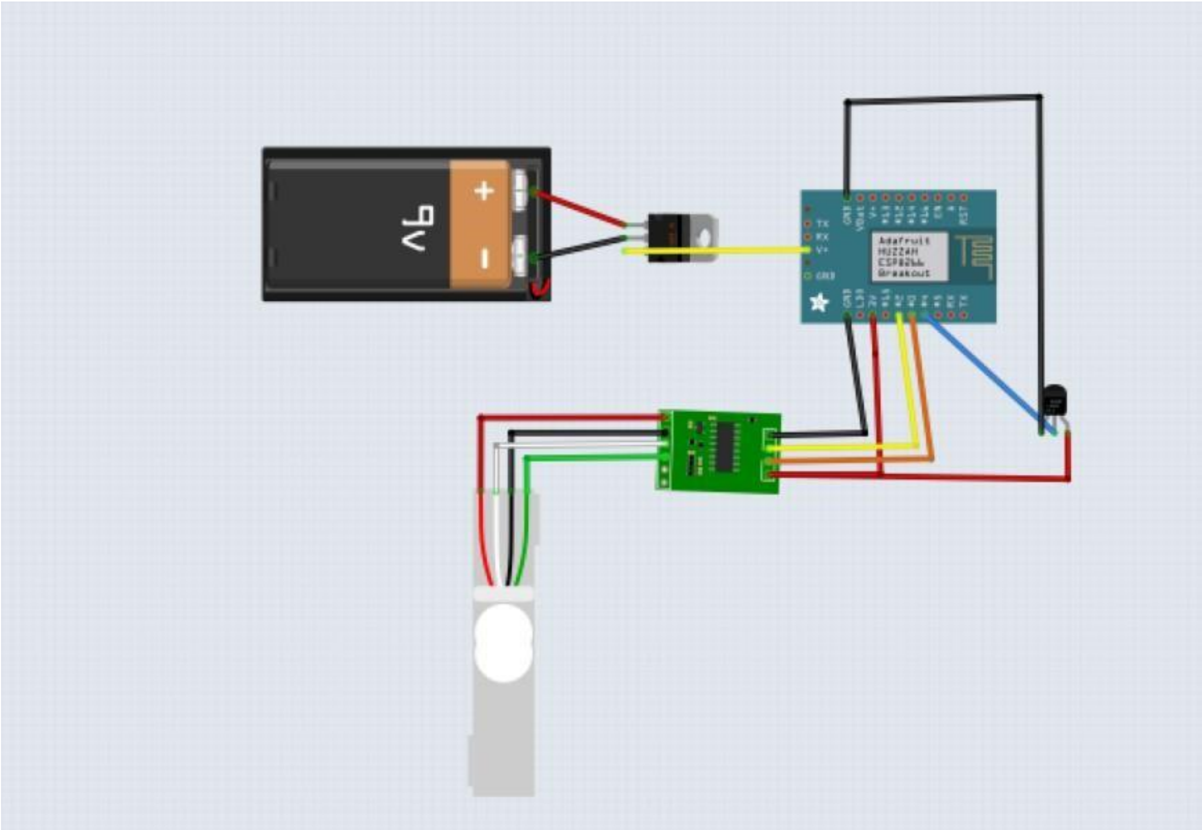


Figure 32: IoT Circuit

Data Acquisitic Weight and Temperature) → Thing Speak Platform → Data Accessible to farmers via Smartphones

The program for sending the data to ThingSpeak platform:

GitHub Profile(Private Repo): https://github.com/shivu926/FishDeboning

6.4 Python: Algo for Fish Head & Tail Detection

The program for detecting head and tail of fish uses IR Sensors controlled through a Raspberry Pi Module, the delay for switching on/off the motor for beheading is calculated using a time counter.

Pseudocode:

1. Specify RPM of Conveyor belt
2. Put fish on belt
3. Fish sensed by IR Sensor, range will be varied by potentiometer
4. Start time counter for calculating the total rise time of sensor signal
5. Time obtained in seconds
6. Calculate length of fish by (RPM * Time)
7. Head length is 0.23 of total length of fish
8. Find head length = 0.23* (length of fish obtained)
9. Calculate delay for cutting head = head length / RPM
10. Switch on motor for cutting head after specified delay
11. Calculate tail length = standard length - Measured length
12. Calculate delay for cutting tail = (tail length / RPM) + t
13. Switch on motor for cutting tail after specified Delay

Code available at: https://github.com/shivu926/FishDeboning

6.5 Human Machine Interface

The HMI is placed at the starting of the machine for the operator to decide whether the desired output is fillet or deboned mush.

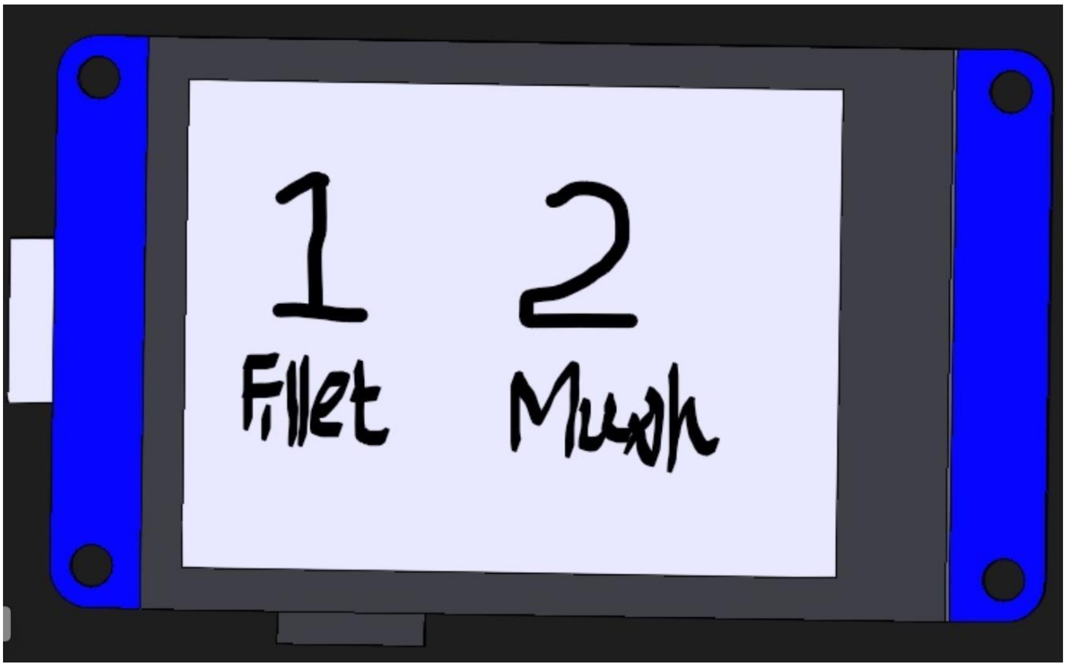


Figure 33: HMI

Depending upon the choice the output will be produced.

```
            Connected of STM32 Controller


int x;
printf("%%s", "Enter the choice 1. Fillet 2.Mush") scanf("%d",x);
switch(x):
{ case
1:
            GPIO.output(Motor9.HIGH);
          break;


case 2:

            GPIO.output(Motor9.LOW);
          break;


Default:
        GPIO.output(Motor9.LOW); break;




}
```

6.6 Cost Analysis

Component	Quantity	Total Price(Rupees)
100V Industrial Motors	13	35000
220V Industrial motors	1	6000
Full wave rectifier	1	500
PWM Controller	14	5000
H-Bridge	14	5000
DC Speed Controller(Control System)	1	3500
ESP8266	1	450
9v Battery	1	300
Voltage Regulator	1	30
HX711-Amplifier	1	80
Load Cell	1	300

HMI	1	200

Total Price = INR 57,000 Electricity Price = Machine Rating (1293-Watt hr)

7. Cost Analysis of the Machine

Cost Analysis of fish processing machine
Assumptions -

- The machine is run 6 hours per day (possible when a community buys one machine for common use or the machine is used by large scale fish processors).
- Electricity cost is assumed to be in line with agricultural rates in Uttar Pradesh
- The cost per fish is divided over a period of 5 years of machine working

Cost Breakdown -

Motors, Iot and sensor	Electronic report	₹ 57000
Manufacturing and Materials	15 Kg Aluminium Stainless steel Blade Conveyor belt Fabrication cost	₹ 25000
Assembly cost	3 hours of Assembly in India	₹ 500
Maintenance cost per year	2.5 % of Total cost	₹2000
Total cost	**Capital cost**	**₹85000**
Running cost per minute	Electronic report	₹.1
Total Cost per day	5 year working period	₹ 110
Total cost per Fish	30 Second processing time	₹.16
Cost benefit per fish by this machine	Assuming processing increases the value by ₹ 5 per fish	**₹4.84**
Break even period for 12 hours running time every day **(processor level)**	Period for the machine to pay itself by profit generated by it	**48 days**
Break even period for 6 hours running time every day **(community level)**	Period for the machine to pay itself by profit generated by it	**97 days**
Break even period for 1 hour running time every day **(individual level)**	Period for the machine to pay itself by profit generated by it	**585 days**

Individual breakdown on motor and running cost is available in electronic section of the report

Final summary

The total cost of the machine is **₹85000**.This machine is **extremely profitable** for installation in a **community level** and **food processor level**. However, at the **individual level** this has a **very long break-even period** (equivalent to more than 5 years which is the expected lifetime of this machine) and hence it is not recommended for **individual buyers (small scale).**

8. References

- MATLAB Documentation- https://in.mathworks.com/help/matlab/
- Simscape Documentation- https://in.mathworks.com/help/physmod/simscape/
- FritZing Documentation - https://fritzing.org/services/
- K Ogata, Modern Control Engineering, Pearson, 2004