High-speed Heading and Gutting of Snipefish, *Macrorhamphosus gracilis*, an Underutilized Species

J. KNYSZEWSKI

Introduction

World fish consumption could be more than doubled if the presently underutilized or unused fishery resources were brought into the human food chain (Grantham, 1981). These resources, generally small pelagic species, remain unused not through lack of harvest technology but through the inability to transform them into stable and acceptable products and to distribute these products to consumers at a price they can afford.

Developments in minced fish technology could make a major contribution to increase exploitation. Minced fish is the flesh separated from the skin, bones, scales, heads, and viscera. The quality of fish mince depends not only on the raw material, but also on the nature of the separation process. Many methods have been applied to a wide range of mince products, although few are established commercially.

In a process described by Miyauchi and Steinberg (1970), the fish is beheaded, eviscerated, washed, and then passed through a machine that separates the edible muscle tissue from the skin, fins, and bones. These heading and evis-cerating processes are extremely costly for small fish. Thus, most separation techniques are based on the whole fish by physically screening flesh from non-flesh components through a perforated filter. However, contamination by visceral material from ungutted fish can cause extensive proteolysis of the mince. Darkening of the mince can be caused by blood and head and gut contents. The viscera may also be associated with aesthetic aspects of taste and texture. Microbiological factors must also be considered when ungutted fish is used as a raw material (Grantham, 1981).

High-speed mechanized heading and gutting could solve these problems if the fish are properly oriented and arranged and fed automatically and speedily through the machinery. This study was designed to explore ways to orient and arrange uniformly an underutilized species, the snipefish, *Macrorhamphosus gracilis* (Fig. 1). We also sought to design, construct, and test a prototype of a commercial high-capacity heading and gutting machine for this species.

There are already some automatically fed heading and gutting or rodding or filleting machines developed by the Baader[1], Arenco, and Trio firms. Those process fish (i.e., herrings) over 20 cm in length, but their speed is only about 225 fish/minute maximum. A rodding machine used for Baltic sprats has a maximum capacity of about 1,100 fish/minute, but the fish are randomly oriented with the back uppermost, and the unit is not able to feed heading and gutting machines.

Materials

Snipefish, used in all experiments, inhabits the Portuguese and adjacent coasts (Brethes, 1979; Bakanev, 1985). Some surveys show it to be the most abundant species in Portuguese waters (IMR, 1978), and the entire catch (about 20,000 t/year) is converted to fish meal. The low harvesting level, at about 20

Jan Knyszewski is with the Mechanical Engineering Department, Technical University of Gdansk, Ul, Majakowskiego 11/12, 80-952 Gdansk, Poland.

[1]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

ABSTRACT—A process and scale-model machine have been developed for automatic heading and evisceration of the snipefish, Macrorhamphosus gracilis, *by utilizing its shape, abdominal cavity, structure, and skin texture (roughness). An arc or semicircular cut has been applied to heading and eviscerating. The parameters for a commercial prototype machine were also investigated and are discussed.*
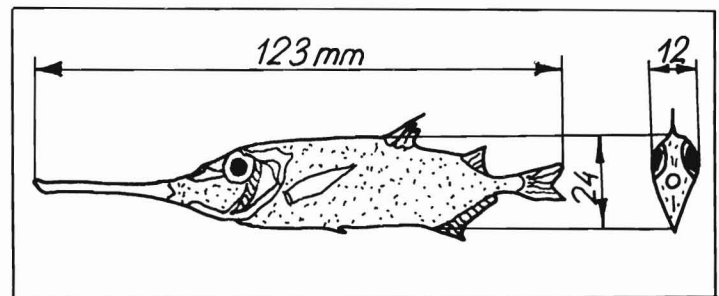
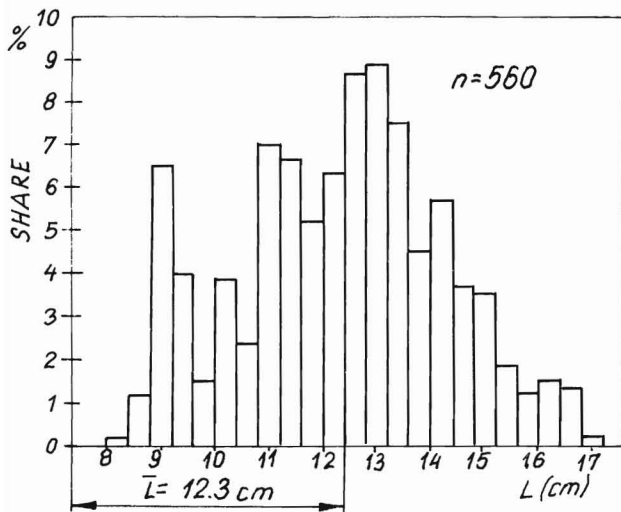Figure 1.—The snipefish, *Macrorhamphosus gracilis*.

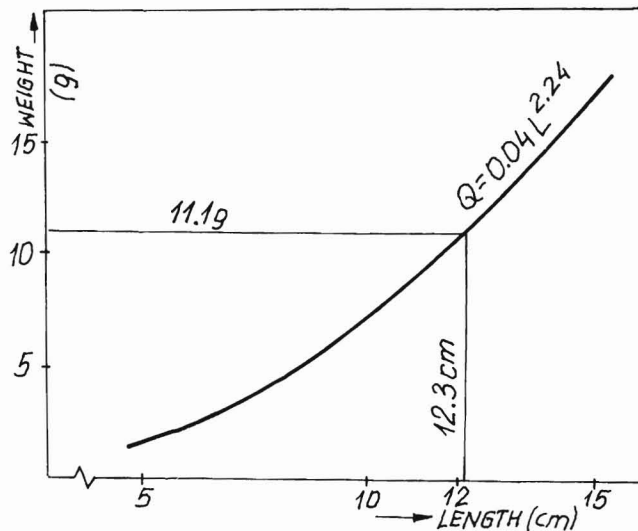Figure 2.—Snipefish length distribution.

Figure 3.—Weight-length relationship of snipefish.

percent of capacity (Morais, 1981; Cadima, 1978; Santos and Moura, 1979), is mainly due to the lack of methods to process the species into acceptable products for human consumption.

Minced flesh from headed and gutted snipefish would appear to offer the best prospects for greater utilization. Calculations[2] made at the Instituto Nacionale de Investigacao das Pescas (INIP) in Lisbon suggested that an automatically fed heading and gutting machine capable of producing about 1,660 snipefish/minute (100,000 fish/hour) could assure economical operation.

The mean length of the snipefish is about 123 mm (Fig. 1). Its body is extended, with a long rigid nose of about 30 percent of its total length. The average body depth is 24 mm, and the average thickness is 12 mm. Length distribution from two catches is presented in Figure 2, and the length-weight relationship is shown in Figure 3.

A survey of the snipefish body suggested an opportunity for devising a fast heading and gutting process. A longitudinal view (Fig. 4) shows the structure and position of the abdominal cavity, and along curve A-B it is possible
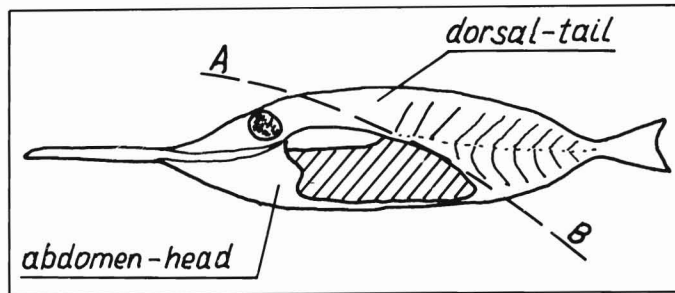

Figure 4.—Structure and site of abdominal cavity.

to head and gut the fish with one arc cut. That divides the fish into two parts: The dorsal-tail (carcass) section with the most useful flesh portion, and the abdomen-head section. The dorsal-tail portion constitutes about 40 percent of the whole fish (by weight) and the abdomen-head portion is about 60 percent. The mean weight of snipefish is 11.1 g. Assuming a machine capacity of 100,000 fish/hour, the fish weight handled would be 1,110 kg/hour, producing 444 kg/hour of the dorsal-tail sections. This would give 266 kg/hour of pure deboned meat or flesh when a Baader B-694 separator is used. This was the basic assumption for our experimental work[3].

Experiments

Experiments were conducted in four steps or phases. In Phase I, an upper vibration table was developed to orient snipefish initially. In Phase II, intermediate and lower vibration tables were devised for final orientation of the fish. Phase III dealt with the heading and gutting apparatus, while Phase IV brought all the elements together into the complete machine.

Figure 5A.—Upper vibration table.

side view
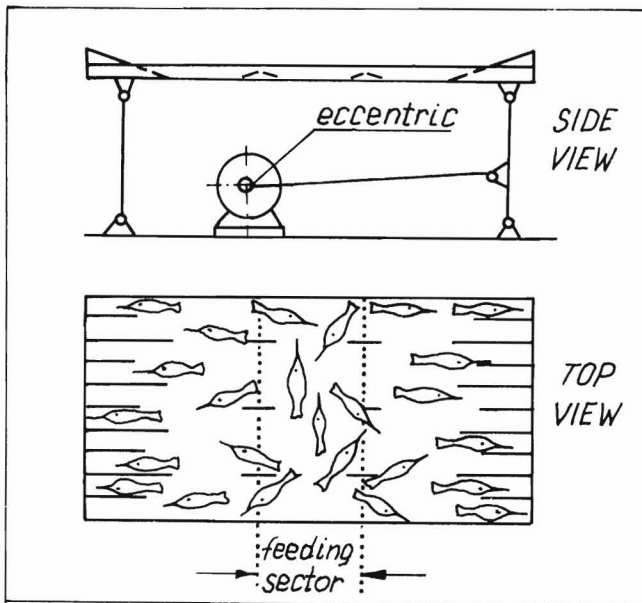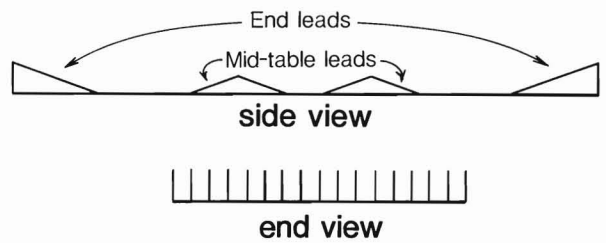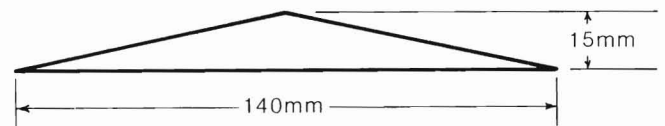
end view

These table-end channels are 33mm wide.

Figure 5B.—Leads and channels on upper table.

x 1mm thick.

Figure 5C.—Dimensions of mid-table trangular leads.

Phase I

The principle of vibration was chosen to orient and propel the snipefish because of its proven effectiveness in the fish and agriculture industries (Carey et al., 1981). The model developed for the initial orientation—the upper table—is shown in Figure 5A. This vibration table is covered with a rough rubber layer and has 17-18 steel plate leads which form short channels at both ends (Fig. 5B). The plate leads are 10 mm high, 1 mm thick, and are 33 mm apart (Fig. 5B). It also has six thin triangular leads in mid-table (Fig. 5B, C).

The upper table is driven (via a connecting rod) by an infinitely variable-speed motor with an eccentric on its axle. The changeable eccentricity (eliptical orbit) was 1.0, 1.5, 2.0, 2.5, and 3.0 mm, producing table displacements of 4.0, 5.9, 7.9, 9.9, and 11.8 mm, respectively. The electric motor speeds were 400, 500, 600, 700, 800, 900, and 1,000 rpm.

Snipefish were fed onto the central feeding sector of the upper vibration table (Fig. 5) in groups of 40-80 fish, repeated from 10 to 18 times. The textures of the table's rubber layer and the snipefish skin made it possible to orient

The upper table with snipefish; note the end and mid-table triangular leads.

and direct the fish nose-first toward both ends of the table. A slight sprinkling of water (about 2 gallons/hour) during experiments enhanced movement of fish toward the ends of the table (excessive water disturbed operations, however). The central triangular steel leads helped orient and direct the fish into the end channels. While samples of fish were fed onto the table, the effects of varied vibration frequencies and amplitudes were studied on the rate of snipefish reaching both ends of the table in proper orientation.
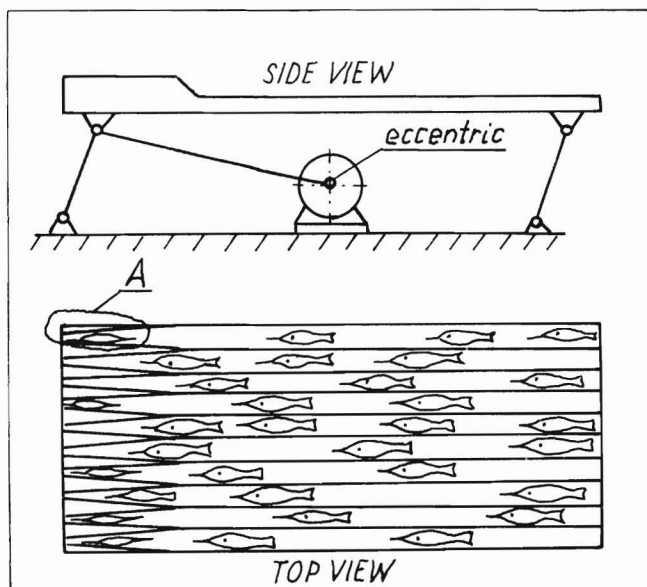
Figure 6.—Lower vibration table.

Figure 7.—Details of the channel "A", enlarged from Figure 6, top; below, proper and improper fish orientation.

Figure 8.—The h_1 and h_2 values of snipefish of different sizes.

Phase II

The fish are discharged nose first from both ends of the upper table and lie at random on either their left or right sides on either an intermediate table or the lower table. The lower vibration table was designed (Fig. 6) to orient the fish and position them back uppermost and nose first. This unit consists of the vibration table, connecting rods inclined at 18°, an infinitely variable-speed electric motor with changeable eccentrics on its axle, a connecting arm, and channels for the fish on the table surface. Eccentricities were the same as in Phase I, but the table displacements were 2.0, 3.0, 4.0, 5.0, and 5.9 mm, respectively. There are two types of channels (Figs. 6 and 7) in the lower table. The first are the plate leads (as in the upper table) which lie along the table. The second type are the converging channels (30 mm high × 1 mm thick) at the end of the lower table which are to turn the fish so their back is uppermost (Fig. 7). (The intermediate table has 18 converging channels and receives fish directly from the upper table.) Two cavities at the base of all the convergent channels make it possible to turn each fish back uppermost because the snipefish, in cross-section,
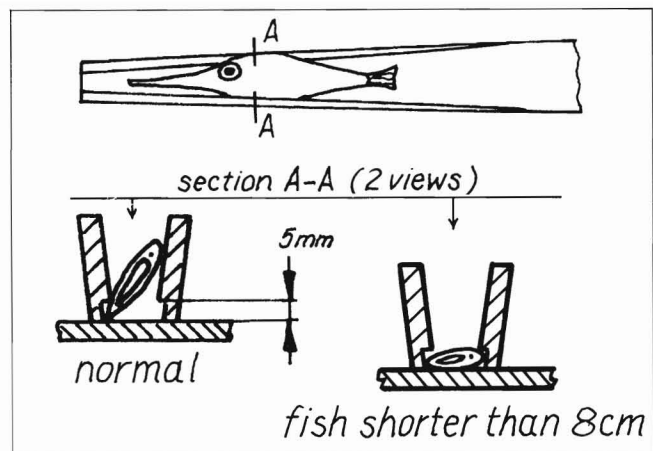
has different measurements (h_1 and h_2) as shown in Figure 8.

In practice, the fish, lying at random on their right and left sides, are fed into the channels at one end of the lower table. Vibrations propel the fish nose-first toward the convergent channels which then turn each fish back uppermost. While the fish moved along, the effectiveness of various vibration frequencies and amplitudes on turning of the fish was studied and measured by the rate of fish turned back uppermost at the end of the convergent channels.
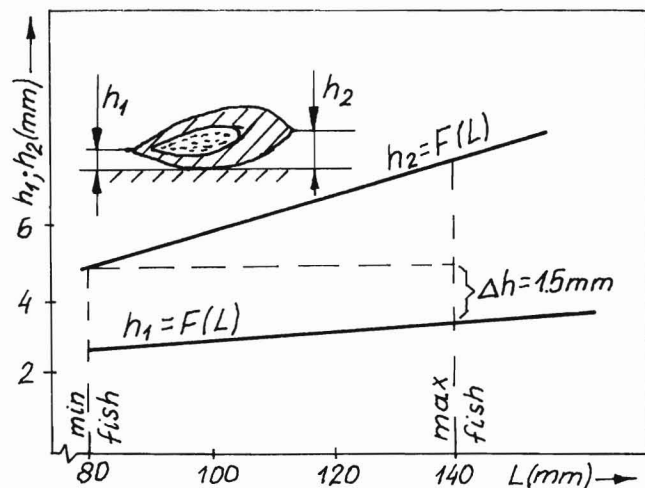
Phase III

Here, we designed and constructed a scale model heading and gutting machine to test the arc cutting of properly oriented, positioned, and fastened fish. Snipefish placed precisely side by side, will lie in a circular position (Fig. 9). This fact allowed us to construct a rotating drum with individual plate rings to correspond with the channels in the intermediate and lower tables. These rings are provided with curved plates which receive and hold each fish (Fig.
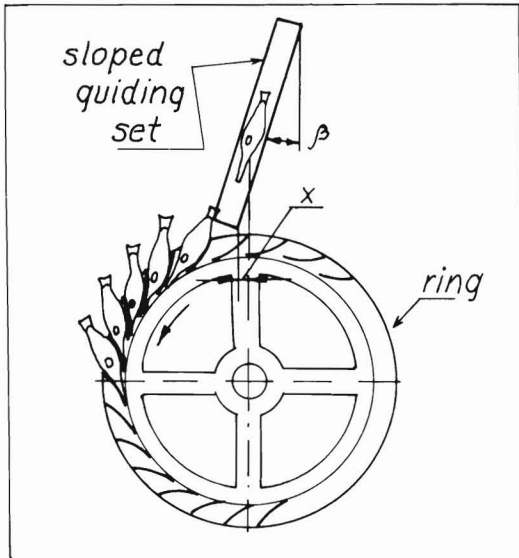
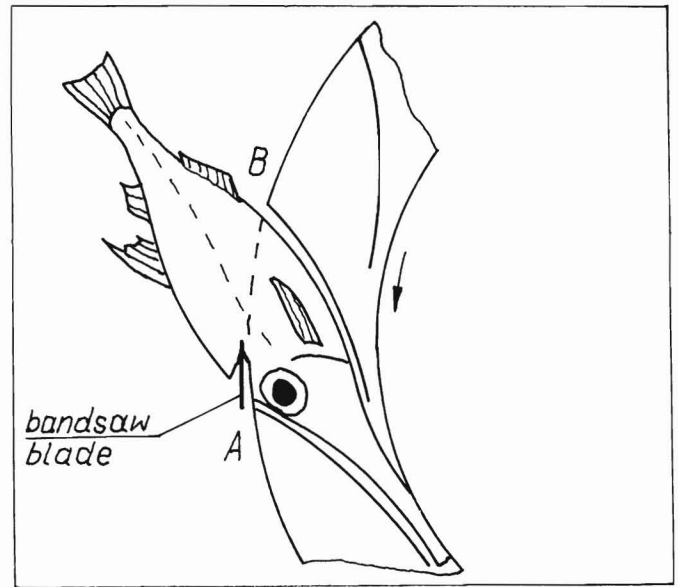Figure 9.—Fish placed in position on one of the rings.

Figure 10.—Scheme of arc cutting.

9). Each ring receives its fish from each convergent channels, via a sloped guiding set (Fig. 9). Altogether, our test machine had 35 channels and 35 corresponding rings on the rotating drum. And, each ring has 25 openings to receive the fish.

The inserted abdomen-head section of the snipefish is held inside the ring opening. A ring edge is approximately equal to the curve A-B (Fig. 4). To cut several fish at the same time, a bandsaw blade (knife) was installed close (0.5 mm) to the rings (Fig. 10). Then, while the drum revolves, the snipefishes in the ring openings reach the knife and the carcass is severed (Fig. 10).

Obviously, the fish must reach the ring openings. This depends on the proper distance to the drum axis and "beta" angle of the sloped guiding set as indicated in Figure 9. While the drum with rings rotated, the bandsaw blade speed and the fish samples were kept constant. The effect of distance "X" and the "beta" angle on the proper and effective positioning of the fish in the ring openings were studied.

Phase IV

After being oriented on the upper table, the fish are more or less separated in two streams, with one going toward
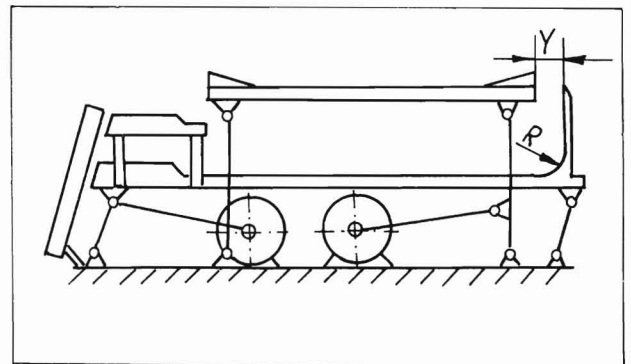

Figure 11.—Test stand showing upper and lower tables with guide (at right) to turn fish onto the lower table.

intermediate table and the drum-ring apparatus. The other stream of fish must then be reversed so it also travels toward the heading and gutting elements, i.e., both streams of fish must feed through the sloped guiding set to the ring openings on the drum. To redirect the stream of fish toward the drum-ring apparatus, another scale model was constructed (Fig. 11). This consisted of the upper vibration table (where initial orientation takes place), the lower vibration table, an attached intermediate table, and a sloped guiding set where both streams

of fish merge. At the end of the table opposite the sloped guiding set, a guide was attached to turn back that stream of fish. There, distance "Y" between the upper vibration table and the guide was measured (Fig. 11). The guide radius "R" had three measurements: 70, 80, and 90 mm. While the fish were discharged from the upper table, the effects of distance "Y" and radius "R" on turning the fish toward the sloped guiding set was studied, and success was measured by the share of fish properly turned back.
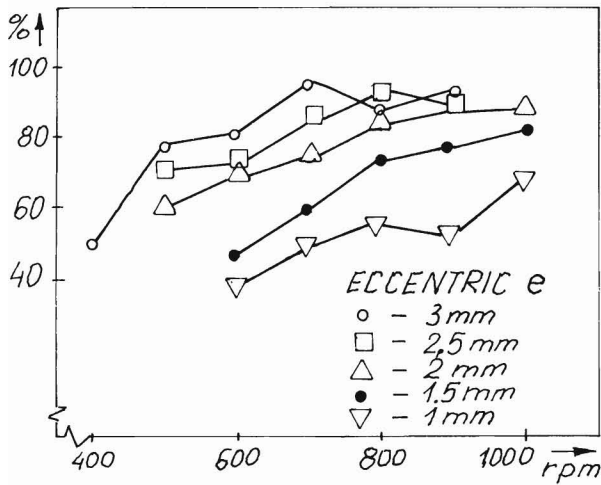
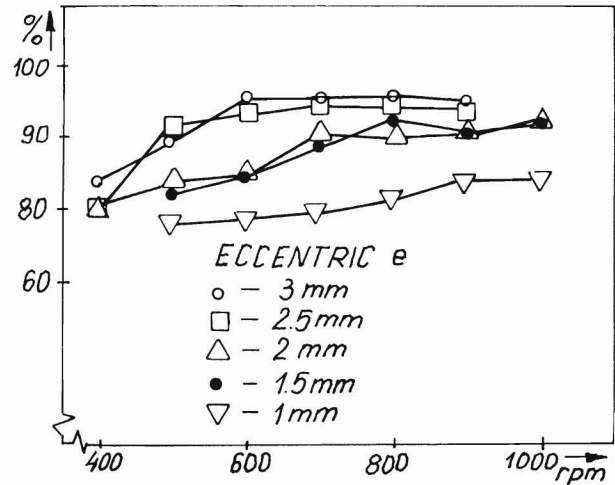Figure 12.—Fish orientation results: Frequency vs. orientation effectiveness.

Figure 13.—Turning snipefish back uppermost in the converging channels: Frequency vs. turning effectiveness.

Results and Discussion

Phase I

About 93-97 percent of the fish placed on the central feeding sector of the upper vibration table turn nose-first and move toward either end of the table (Fig. 12) Some damaged fish (e.g., broken nose or pierced by another's nose) were subjected to different drag forces, at times in opposite directions. Fish with damaged belly cavities adhered to and stopped on the table. Fish travelling in opposite directions met and their movement tracks were disturbed.

The effectiveness of the orientation and movement depends also on the amplitude and frequency of vibrations. The greater the amplitude is, the lower the frequency is needed. Greater effectiveness was noted at larger amplitudes. When frequency increased above the optimum, interferences appeared and effectiveness gradually deteriorated. Excessive forces can cause fish movement paths to change which can sometimes induce fish circulation. And, when the amplitude is too great, the machine itself can be subjected to excessive mechanical forces and stresses.

Phase II

Traveling nose first on the lower table, the snipefish enter the channels where greater resistance to movement occurs. To keep the fish moving, greater vibra-

Figure 14.—Ring insertion accuracy: Beta angle and distance X (Fig. 9) vs. hitting effectiveness.

tion is induced with the connecting rods (Fig. 6). Generally, the greater the frequency and amplitude are, the greater is the vibration force; however, above the optimum level, fish movement becomes erratic, and sometimes they bounce, reducing the efficiency and speed of the process.

About 92-98 percent of the fish were properly oriented (Fig. 13). Fish >16 cm have a body depth greater than the channel width which prevented proper forward movement. And, fish <8 cm stopped in the converging channels be-

cause dimension h_2 was less than 5 mm (Fig. 8). Fish with full stomachs were more round in cross-section, like a mackerel, which caused them to be improperly oriented too.

Phase III

About 90-97 percent of the fish fed to the table at random were effectively oriented (Fig. 14) for an "X" distance of 10 mm and an 18° "beta" angle. Effectiveness gradually declined as the "X" distance increased or decreased. An increased "beta" angle caused the
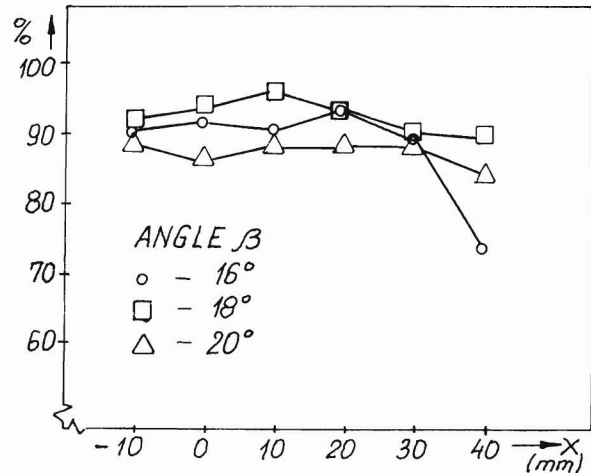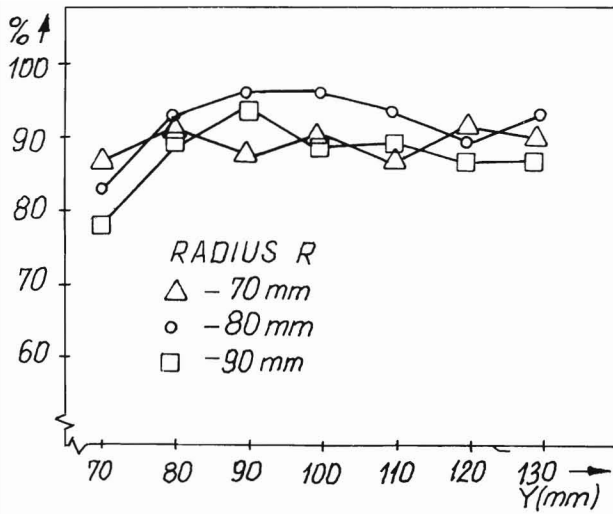
Figure 15.—Turning fish onto lower table: Distance Y (Fig. 11) vs. effectiveness.

fish to jump out of the ring openings. A decreased "beta" angle resulted in some problems with the fish reaching the openings and exiting the sloped guiding set.

Phase IV

During experiments to turn the fish onto the lower table (Fig. 11), a radius "R" of 80 mm was found most effective and a distance "Y" of 100 mm gave about 96 percent effectiveness (Fig. 15). If distance "Y" increases, it causes the fish to stop on the bottom of the guide. If distance "Y" is too narrow the fish nose catches on the top edge of the guide.
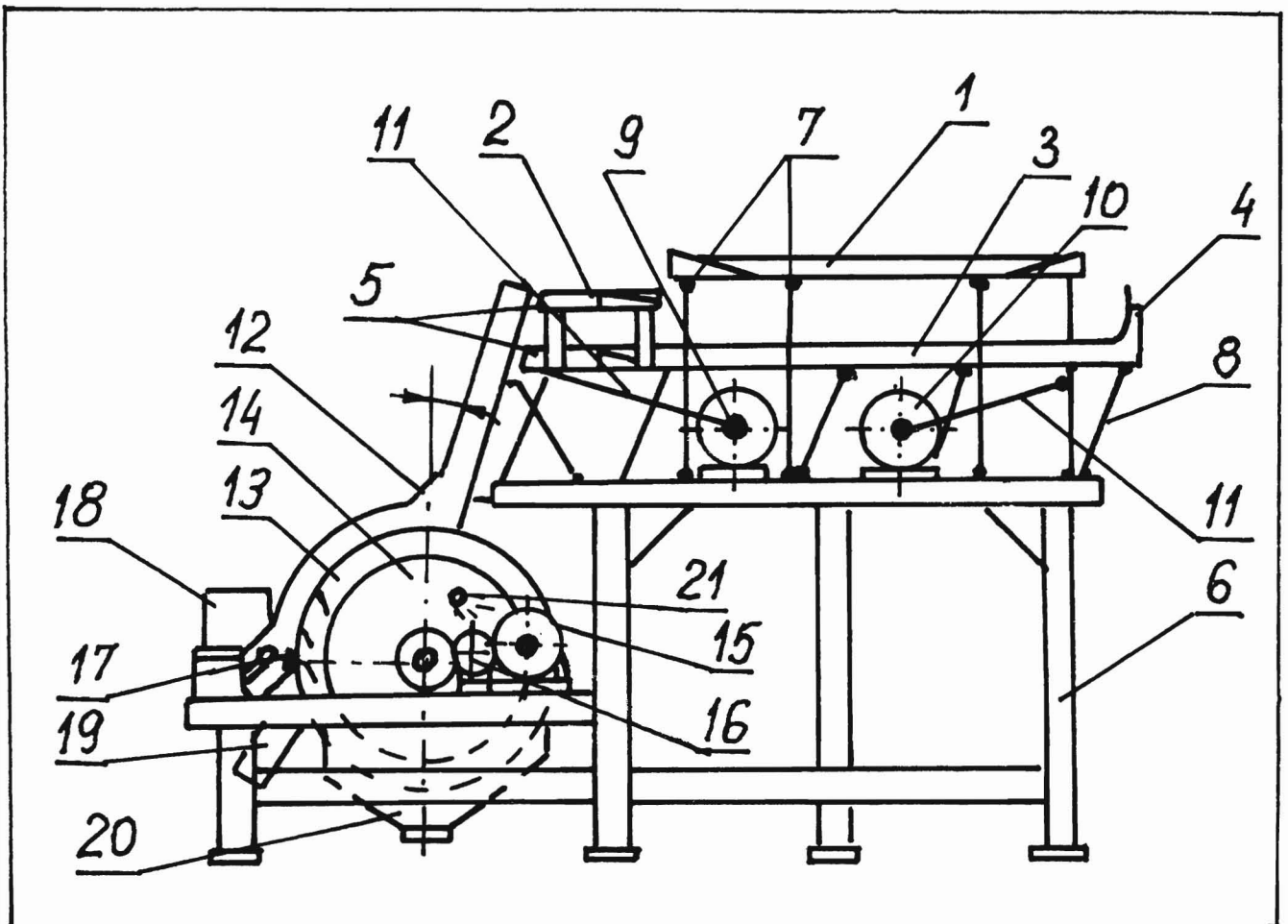

Figure 16.—Pictorial diagram of the entire machine. See text (page 15) for details.

Construction

A prototype of the snipefish processing machine was designed and constructed to meet the following considerations:

1) Capacity of about 1,800 fish/minute,
2) Cutting shape along curve A-B (Fig. 4),
3) Operating range for fish lengths from 8 to 15 cm,
4) Fish supplied by conveyor,
5) One-person operation.

The prototype machine (Fig. 16, 17[4]) operates as follows[5]: The fish are fed at a controlled rate at point A onto the upper vibration table (1)[6]. After orientation, the fish are discharged nose first onto an intermediate vibration table (2) from one side and onto the lower vibration table (3) from the other. A revolving guide (4) turns and directs the fish toward the converging channels (5) (18 above and 17 below) which turn the fish back uppermost. The vibration tables are attached to the machine frame (6) by the connecting rods (7 and 8). The tables are driven by electric motors (9 and 10) through the eccentrics and connecting arms (11). Finally, the fish are discharged from the converging channels of the intermediate and lower vibration tables into the sloped guiding set (12). The sloped guiding set feeds the fish into the openings of the rings (13) which are fixed on the drum (14). The drum is driven by an electric motor (15) through a reduction gear (16). While the drum revolves, the fish enter the openings and reach a bandsaw blade (17)

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[4]The commercial prototype of the machine was constructed by Industrias Nacionas de Defesa E. P., Lisbon, and has been tested at INIP, Lisbon.
[5]Knyszewski, J. Polish patent appl. no. P. 245727.
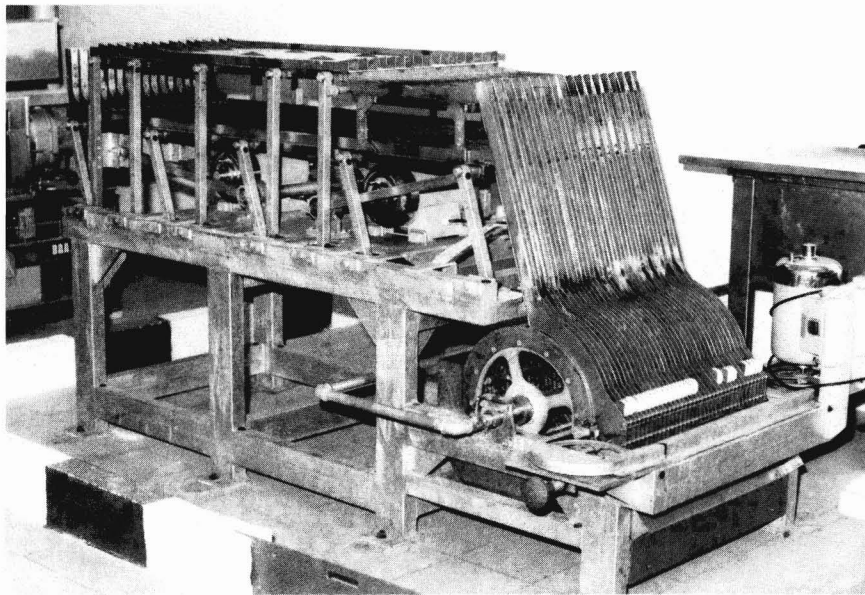[6]Numbers in parentheses correspond to the numbers on Figure 16.

Figure 17.—The commercial prototype machine.

where they are severed. The bandsaw is driven by an electric motor (18). Upon removal, the dorsal-tail sections exit (19) onto a shuttle while the abdomen-head sections drop through another opening (20). A flow of water (21) enhances cutting and removal of abdomen-head sections from the openings.

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