# DESIGN AND DEVELOPMENT OF AN AUTOMATED CAN FILLING SYSTEM FOR FISH

By

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B.Eng., Panjab University, Chandigarh, India, 1991

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF APPLIED SCIENCE

in

THE FACULTY OF GRADUATE STUDIES

DEPARTMENT OF MECHANICAL ENGINEERING

We accept this thesis as conforming

to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

September 1996

# Abstract

Salmon processing is a five hundred million dollar industry in British Columbia. This research is a part of the work undertaken in the Industrial Automation Laboratory at the University of British Columbia to develop advanced, low-cost technology for flexible automation in the fish processing industry. The scope of the research reported in this thesis is limited to the design and development of an automated can-filling system for fish. Higher operating speeds, improved filling accuracy and waste reduction, better versatility and process flexibility, improved product quality and presentation, and a greater level of automation are some of the key objectives of the research. These are addressed in the thesis.

The performance of the existing special purpose machines is examined in detail to identify problem areas and their possible causes. Alternative conceptual designs are studied, that would eliminate these problems. An appropriate design is chosen and further analyzed and developed. The particular design chosen uses weight-based portion control of fish as opposed to the existing volume-based processing and portion compacting. This new approach is expected to provide improved accuracy and product quality. The proposed design for an automated can-filling system is developed up to the stage of component specification and selection that would meet the industrial requirements. Also, a cost-benefit analysis is made for the proposed can filling system, with a critical comparison with the existing technology.

Laboratory experiments have been carried out to check the suitability of the design. In particular, an experimental prototype for the filling system has been designed, built and employed to test the filling effectiveness of the proposed system. The experimental results are evaluated and further improvements are recommended for the can-filling system.

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## Acknowledgment

I would like to thank Dr. C. W. de Silva and Dr. E. Croft for their constant supervision and guidance throughout this research. The funding for this research is provided by the Natural Sciences and Engineering Research Council's Industrial Automation Chair held by Dr. C. W. de Silva and through Garfield Weston Foundation. Additional support from B.C. Packers Limited is also appreciated.

Also I would like to thank Mr. Harold French, whose expertise in the can-filling machines manufacturing industry was particularly helpful for better understanding of the existing machinery and associated problems. I would also like to thank my colleagues - Farag Omar, Matthew O'dor and Boyd Allin, who are currently working on the various aspects of the can-filling project, for the their active participation in the brain-storming sessions particularly during the conceptual phase of the design. Special thanks also go to Mr. Scott J. Gu for helping me with the design of electronic control circuits for the prototype filler.

# Chapter 1

# Introduction

The objective of the present work is to design and develop of an automated can-filling system for fish. Higher operating speed, improved filling accuracy and waste reduction, better versatility and process flexibility, improved product quality and presentation, and greater level of automation are the key objectives of this research. The can filling machinery used in the modern salmon canneries dates back to 1930s. A brief history of the development of these salmon canneries [1] is presented in Section 1.1. The existing can-filling machinery and associated problems are described in Section 1.2. The motivation and objectives of undertaking this research are presented in Sections 1.3 and 1.4 respectively. The thesis organization is presented in Section 1.5.

## 1.1 History of Salmon Canneries

The origin of the salmon canning industry dates back to the early 19th century. The world's first salmon-cannery was established in Cork, Ireland by the British firm Crosse and Blackwell. The North American canning industry emerged from the U.S. vegetable and fruit canning industry of Baltimore, Maryland. The canning of fish, especially cod, was pioneered in North America by Ezra Daggett of New York, in 1819. A Canadian named Tristram Halliday was canning salmon at St. John's, New Brunswick, as early as 1839. In British Columbia, James Syme was the first to experiment with canning on Fraser River in 1839. The period between 1871 and 1873 saw the establishment of small canneries on the river on permanent basis.

Between 1871 and 1903, the canning process was carried out manually, starting with butchering. The fish were butchered manually. It was not unusual for a worker to clean as many as thousand fish a day. The cut portions of fish were manually placed into the cans. The fastest known filling speed in the manual operation was estimated at three cans a minute. The filled cans were then manually soldered and boiled in a kettle. These manual processes were recognized as chief bottlenecks of the industry. In the earlier canneries, the cans were essentially hand made. By 1890, a number of machines were introduced to punch out the pieces from sheet metal which would form the lids and the containers, and soldering machines were developed as well. In 1897, an automatic can-making machine was introduced by the Automatic Can Factory of New Westminster, B.C., the largest and best-equipped can factory north of San Francisco. With this machine it became possible for the canneries, which otherwise would run out of cans due to poor planning or a large run of fish, to quickly replenish their stocks. Another major innovation was the introduction of steam retort in 1877 for cooking the sealed cans of fish, which further facilitated the canning process by significantly reducing spoilage due to faulty cooking. With steam retorts, it was possible to cook the products at higher temperatures than was possible with boiling water containing dissolved calcium chloride. This accelerated the cooking process and eliminated other problems such as the bursting of cans and the rusting caused by the calcium chloride. Furthermore, the large horizontal salmon retort was a major labor saving device as it not only took a larger charge but was fed by trucks on rails running directly into the retort.

Another major development was the introduction of a soldering machine in the late 1870s. It reduced the labor requirements because each machine could produce 3,000 cans in a ten-hour day as compared to 1,000 cans per ten-hour day under the old manual system. During the early 1880s, major contributions were made in the cutting, filling and salting processes, and in the movement of cans through the cannery. The concept of gang-knife cutters was introduced in 1881. The machine was hand driven and consisted of eight blades, uniformly spaced so as to cut the fish into sections which were the exact height of the can, allowing for some clearance. Conveyor belts were also introduced to speed up the line. There were three main reasons for the clustering of these innovations during the period of 1877 to 1880s;

namely, extensive capital investment, introduction of steam retorts, and labor shortages. In 1889, a more sophisticated gang-knife cutter was introduced, which consisted of a set of crank driven revolving knives. The year 1891 saw the introduction of half-pound cans. The cans were packed 96 to a case so that the case would equal in weight to a previous one with 48 one-pound cans. The effect of these technological innovations can be seen from the fact that in 1877, the average production per day ranged from 240 cases with a crew of 130 to 150 men to 300 to 450 cases with an average crew of 150 to 300. By 1883, the average daily production had risen to 1,000 cases with an average crew of 120 to 140. Between 1893 and the early 1900's, although the average daily production remained the same, the size of the cannery crew decreased from 120 to 150 to 80 to 90.

Between 1903 and 1913, the industry became dominated by large corporations having a high degree of centralization. Many small canneries were closed or merged with the bigger ones. Scarcity of labor and increased operating costs during the period from 1905 to 1909, led to further innovations. The Smith Butchering machine, which came to be known as the Iron Butcher, was introduced in 1906. This machine could process 60 to 75 fish per minute with the assistance of three workers, whereas the system it replaced was capable of processing only 1,500 to 2,000 fish in a ten-hour day with the help of 30 workers. It also helped reduce the wastage. It was estimated that the saving of meat by using an Iron Butcher was about half a fish per 48 pound case. Another innovation during this period was the application of electricity as a source of power and light. In particular the steam engines were replaced by electric motors. In 1912, the advent of sanitary cans and double seamers eliminated the need for soldering of can lids. Various machines were developed for filling. One of the earliest machines was the Jensen filler built by Seattle - Astroia Iron Works. This machine used a single filling chamber and a plunger. Another machine, called Rooney Filler, was a single plunger turret indexed machine. It used a system of cams to perform each operation, and was capable of filling 25 to 45 cans per minute. The Fulton filler, developed in 1902 and later refined in 1911, was capable of filling 60 cans per minute. Weighing and salting were mechanized for the first time during this period. With the salting machine a measured quantity of salt was put into each can by a hopper system. This machine, driven by the can-filler, was timed to salt each can as it was processed by the filler. Various mechanized weighers were introduced. The most successful, the Smith weigher, was capable of weighing 48 cans per minute.

Major improvements in the can-filling operation took place in the early 1930's, with the introduction of the American Can Company's model II and model III fillers. In these new machines, the fish were placed on a intermittently moving spiked chain, and an elliptical cut-off knife was used to slice the fish into portion lengths. A spring loaded pusher fork then forced these portions through a twister tunnel (90° bend) to orient the portions with the backbone in a vertical position. A six-pocket vertical rotary unit received both the portions and the cans simultaneously. The portions were pressed into each pocket with a spring loaded pusher fork. A cut-off knife was used to slice-off each volumetrically measured pocket-sized portion which was later deposited into a corresponding can by means of a plunger. The speed of the cutter unit was regulated by a cork slip clutch activated by a hydraulic slave cylinder which sensed the pressure through the pusher fork. The machine was capable of filling up to 125 cans per minute. Around the same period, the Continental Can Company introduced Troyer-Fox filler. Major difference between the two types of fillers was vertical packing in the American Can Company's fillers compared to horizontal packing in the Troyer-Fox fillers. Later on, the model IV introduced by the American Can Company incorporated a rotary gang knife cutter unit and rotary cut-off knives, both of which were mounted on ball bearings. As a result, bushings, sliding blocks, and associated lubrication problems were eliminated. An oil-gear transmission unit was used to synchronize the speed of the cutter unit with that of the filler. The Continental Can Company also improved their filler by incorporating an electronically sensed variable speed transmission. These new machines filled cans at the rate of 240 to 300 per minute. The operating principles of the American Can Company machine have not changed in 60 years. The details of the machine operations are more completely described and illustrated in Section 1.2.1.

## 1.2 A Typical Can-Filling Plant

It is important to have a thorough understanding of the working of the machinery in the existing fish canning lines in order to identify the problems associated with them and their possible causes, with a view to design improvements. In a typical cannery, the main operations are as schematically shown in Figure 1.1.

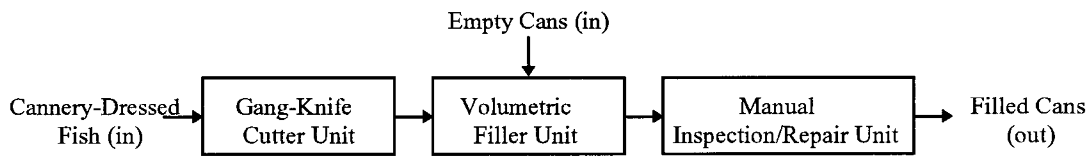



**Figure 1.1** An Existing Fish-Canning Line.

### 1.2.1 The Existing Machine

The raw fish are placed on a conveyor in a specific orientation. The conveyor takes the fish to a head-removal machine known as the "Iron-Butcher". Here, a mechanical arm positions the fish in relation to the cutter. However, the iron-butcher itself has problems; for example, the faulty placement of fish may result in undercutting (an incomplete cut) and overcutting (loss of valuable meat) [2, 3, 4]. Next, the head-removed fish are sent to another machine for the removal of tail and fins. The internal organs and remaining roe or milt are taken out from the fish through a gutting operation, either manually or by using a machine specifically designed for that purpose. The resulting product, called cannery dressed fish, is now ready for the canning operations.

The cannery dressed fish are fed into a cutter unit consisting of gang-knives, as shown in Figure 1.2. A cutter unit may feed more than one filler. Two to four workers feed the fish into the cutter unit. The function of the cutter unit is to cut the fish into equal sized portions of equal height, that is equal to the height of the can minus the required head clearance. Water spray nozzles placed on either side of the cutter lubricate the cutting process. In case of 1/4 LB cutting, the portions automatically orient themselves in the stable (desired) position because the cut-widths of each portion is usually smaller than its cross-section. In the case of 1/2 LB or 1 LB machines, however, a 90 degree twist tunnel is used to orient the portions into a vertical position.

Three workers carry out tasks between the cutter unit and the filler. Their primary tasks are to regulate the flow of portions, to properly orient them (to prevent skin and bones appearing on top of a can), and to avoid any overlapping of steaks, thereby ensuring a smooth consistent flow of fish portions into the filler-unit. Any suspicious looking portions, e.g., ones with blood stains, or parasites, and tail ends, are removed at this stage. The last worker's task is to pack the portions closely on the conveyor. These closely packed portions are made to pass underneath another conveyor, to ensure uniform packing without unacceptable gaps.

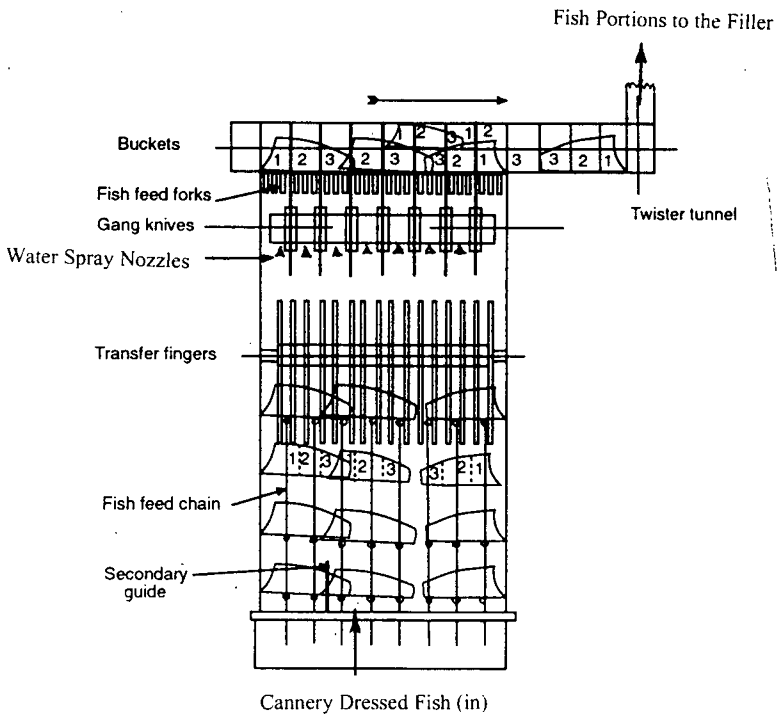
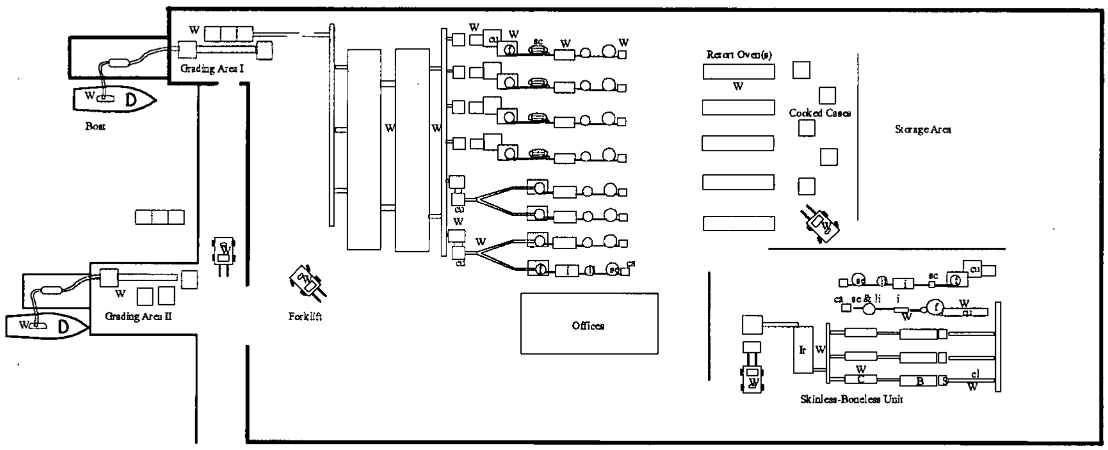



**Figure 1.2** Gang-Knife Cutter Arrangement in the Existing Machinery.

Next, the portions are forced into the filler pockets on a rotary turret as the individual pockets reach the front of the tunnel, as shown in Figure 1.4. This is a type of volumetric filling. Each pocket has a movable half, which closes while filling, thus forming the desired cylindrical shape. Excessive meat is forced out of the pocket during this cylindrical forming, and is cut by a rotary-knife. A reciprocating plate (follower slide) assists in this process. The empty cans are continuously fed into the machine from one side, by gravity. Some salt is placed in each can before the filling is carried out at the filler unit. A synchronizer speeds up the cans to facilitate their entry into the filler unit. The formed portions of fish are then pressed into the cans which pass underneath the pockets, by means of cam driven plungers. The disintegration of fish portions during forming, cutting and filling operations results in a considerable amount of useful meat being wasted in the form of a slurry. As the filled cans come out of the machine, the slurry is washed out from the sides of cans by means of water jets. Underweight cans can be detected by a weighing system, at this stage.

The filled cans are then conveyed to an inspection / repair table. Four to five workers, standing on both sides of the table, look for any poorly filled cans ( e. g., the underweight cans, cans with skin, bones appearing on top or pieces projecting out). They remove and repair (patch) cans based on their visual-judgment and experience. Small precut portions of fish are packed into the underweight cans. Off-line mechanical scales are used for this purpose. Similarly the appearance problems are rectified at this stage, before the corrected cans are returned to the main line. Filling speeds of 220 to 250 cans/minute are typical for these filling machines with the filling accuracies within $\pm 5\%$ of the target weight. The filling-machine performance is worse in the case of skinless-boneless salmon, because no special purpose machines are available for canning that particular product. Some canneries rely on tuna fillers for this purpose; however, these machines are excessively wasteful . A typical cannery layout is shown in Figure 1.3.




Glossary:

**cu** Gang-Knife Cutter Unit
**f** Filling Machine
**i** Post-Filling Inspection and Repair
**li** Lid Placement Machine
**Se** Seamer
**Ir** Iron Butcher
**C** Cleaning Machine
**cl** Fillet Cleaning Area
**sc** Mechanical Weighing Scales
**ca** Case (Filled Cans)
**W** Workers

**Figure 1.3.** Layout of a Typical Canning Plant [2].

### 1.2.2 Drawbacks of Existing Machinery

After a detailed investigation of various operations, associated problems and their possible causes in a fish-cannery, it was determined that the principle of volumetric filling, on which the existing canning machines are based, is the root cause of many of the perceived shortcomings of the canning process. The forces and stresses exerted on the fish portions during the forming and filling operations result in excessive slurry formation and poorly filled cans (i.e., cans with skin and bone appearing on the surface or with bones protruding onto the flanges). The underweight / overweight problem may be attributed to the fact that fish is inhomogenous by nature, and its density may also vary depending upon the habitat, species type, storage conditions, season, etc. In the existing machines, the only way to check the problem of underweight / overweight cans is to adjust the tumbler fork[1] spring pressure (Figure 1.4) or,

[1] The tumbler fork is a mechanism used in the existing machines, to force the portions of meat into the filler pockets.

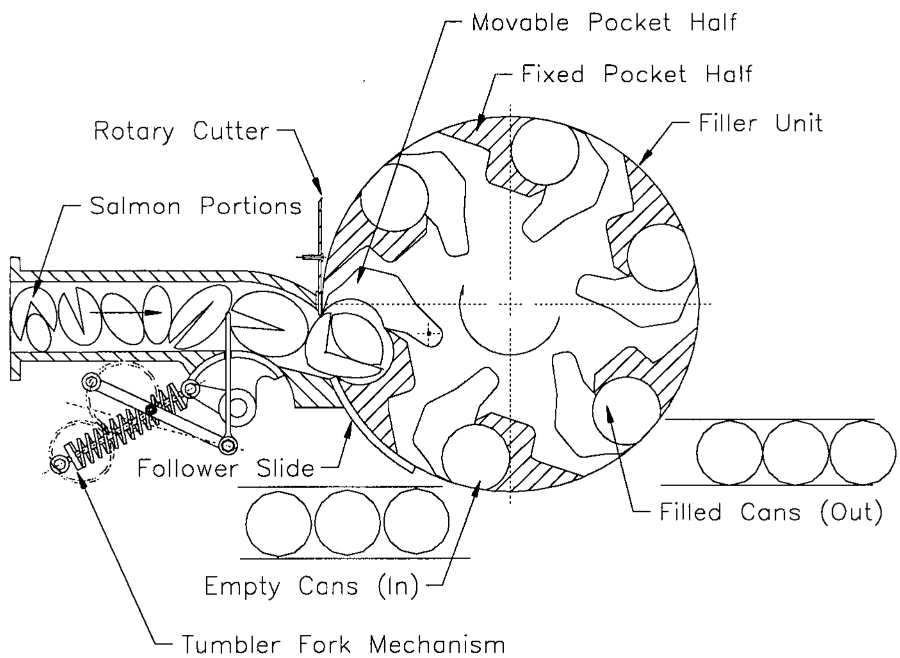



**Figure 1.4** Tumbler-Fork Mechanism that Feeds the Fish Portions into the Filler Unit

alternatively, to increase / decrease the pocket height by adjusting its roof plate. However, the reliability of these manual adjustments depends on the experience of the worker who performs these operations. Furthermore, the adjustments will result in long down-times. The mechanical design of the machine itself limits the speed of its operation. It has been found that the cam rollers wear out quite rapidly if the machine is made to run at speeds greater than 300 cans/minute. Also the filling accuracy is adversely affected at such speeds, and this will overload the patchers, who fill underweight cans.

It follows that the performance of existing machines in a canning line is governed by many factors like the species, size, quality of fish, experience of the workers and other mechanical factors like the flexibility of machine adjustment. It follows that any new design of a canning machine should take into account all these considerations.

## 1.3 Motivation for Research

The salmon fishery is an important industry in several countries. The wholesale value of canned salmon in the province of British Columbia, Canada, for example is several hundred million dollars (See Figure 1.5), which represents about a quarter of the wholesale value of all fishery products in the province.

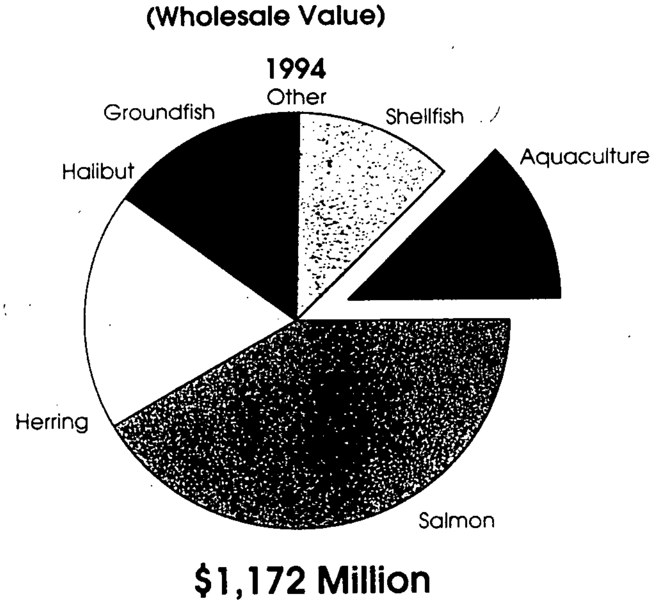



**Figure 1.5** Wholesale Value of Canned Salmon Pack in British Columbia, Canada.

In a typical year British Columbia packs over one million 48 lb. cases, the United States packs about four million cases and Japan about two million. Despite this, technological innovations in the salmon canning processes have been minor. The basic machinery used for steaking, filleting, sealing and retorting has remained virtually unchanged for the last five decades.

In the past decade however, the entire fish processing industry, particularly the salmon fishery has been under pressure for improved productivity. Increasing wage rates in this relatively labor-intensive industry is one force behind this pressure. Other factors include dwindling salmon stocks; the seasonal nature of the industry and competitive market conditions. Automation of fish processing industry is able to address several of these problems through increased recovery, productivity and product quality. A research laboratory has been established [4] to develop the needed technology. In addition to cutting and grading processes, we have initiated a research and development activity in our laboratory for the automation of can-filling operations.

The majority of the machinery in the canning lines, which are in use today, are special purpose devices which are suitable for canning only a particular type and size of the product. For example, canned salmon is available in the market in can sizes varying from 1/4 lb. to 1 lb. They may be produced as either skinless-boneless type or regular steaks. At present, to can each particular variety and type of fish in a specific can size, a dedicated machine is required. Changeover to different sizes involves substantial down-time and cost. Low filling speed, poor filling accuracy, high wastage (See Figure 1.6), costly and complicated manual operations and recurring maintenance costs are some drawbacks associated with these existing fixed-

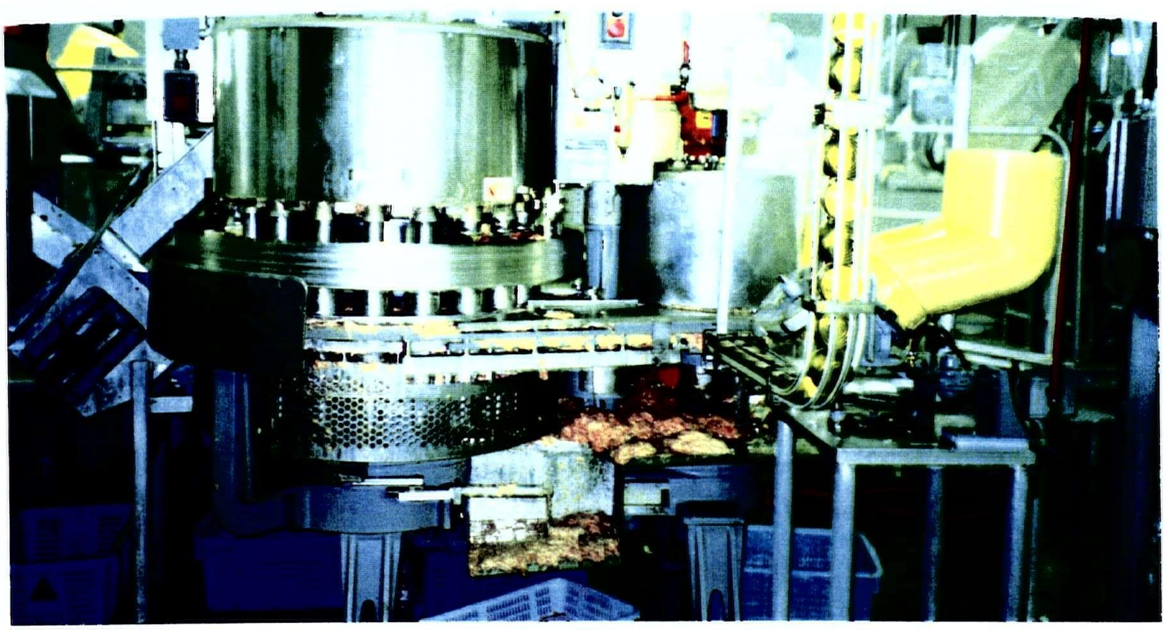


**Figure 1.6** Excessive Wastage Near a Skinless and Boneless Filler.

configuration machines. Moreover, owing to the seasonal nature of the industry, the machines are in operation for only 3 to 4 months of a given year. This makes it difficult for the industry to retain skilled labor on a permanent basis, and the consequence is increased overhead costs in terms of hiring and training new workers. Many of these difficulties can be overcome by using a more flexible type of automation [4, 5], where the canning line is able to automatically adjust to the variety and size of the product. This thesis addresses the flexible automation of a fish canning line.

## 1.4 Research Objectives

The main objective of this research is to design and develop an automated can-filling system for salmon that would eliminate or at least reduce many of the shortcomings of existing machines, as outlined before, and would also satisfy the current industry requirements; in particular, higher operating speed, better filling accuracy, reduced wastage, versatility and automated operation. In the present thesis, these objectives are explored by carrying out the following tasks:

1. **Literature search**

   Before developing a new design, it is useful to conduct a thorough search for existing products, with the objective of determining their characteristics, strengths, and weaknesses. This will help prevent duplication of existing technology or products. Thus, unnecessary wastage of time and resources is prevented and the research and development process becomes more efficient.

2. **Analysis of the existing design**

   The first step of the design process is to become thoroughly familiar with the design features and workings of the machinery that are commonly used in the existing fish canning lines. It is important to identify the problems associated with them and their possible causes.

3. **Conceptualization**

   Once the problems associated with the existing machinery have been identified, the next step is to consider possible design improvements that would reduce or eliminate these problems. Depending on the complexity of the situation, it may involve modification of the existing design or introduction of a new design concept altogether. Ideally, one should gather as many solutions as possible, and then analyze them to chose the "best" according to some criteria.

4. **Development of the final design**

   Once a conceptual design has been developed, it is useful to study it further by building a prototype. The prototyping will involve the selection of materials, design of individual parts and mechanisms, identification of various sensors, actuators, other instrumentation, and integration of the overall system.

5. **Experimental evaluation**

   Next, the prototype should be tested for performance evaluation. If the performance meets the design considerations, the new design could be considered for mass production. If not, further design iterations, prototype improvement and testing would be required.

6. **Cost-benefit analysis**

   Before a final design is selected, implemented and commanded for mass production, a cost-benefit study should be conducted to find out the relative economic advantages of the new design.

## 1.5 Thesis Organization

The scope of the research reported in this thesis is limited to the design and development of an automated can-filling system for fish with the main focus on the filling operations. The present chapter has given an overview of the historical development of salmon canneries in North America. The operation and associated drawbacks of the existing machinery have been described in detail. The objectives of this research and the motivation thereof have been presented as well.

Chapter 2 gives a review of the literature relevant to this research. It presents the state of the art and sets the stage for possible technological developments.

Chapter 3 deals with the conceptual design of a new machine for the can filling process. Various design ideas are presented and analyzed. The objective here is to chose the most appropriate design for a can filling system, by taking into account various design criteria, specifications and constraints.

Chapter 4 describes the design and development of the new machine in detail. Various mechanical and control aspects of the design are presented, by taking into consideration the specific design requirements and practical needs.

Chapter 5 provides a cost-benefit analysis for the new machine. An economic study is made to establish the cost advantages of proposed technology in comparison with the existing processes. This will provide an economic justification for the proposed machinery and procedures.

Chapter 6 describes the development of a laboratory prototype and various experiments that had been conducted to verify the new design.

Chapter 7 summarizes the thesis, highlighting the accomplishments. Also, in view of the limitations of the new design, recommendations are made for future work.

# Chapter 2

## Literature Review

The objective of the research presented in this thesis is to design and develop an improved and automated can filling system for fish. The problem can be divided into separate tasks; specifically: pre-filling, filling and post-filling operations. The pre-filling operation involves the cutting of fish into can filling portion amounts, and it may involve the grouping of two or more portions to achieve the desired target weight. Hence, the pre-filling task may be considered primarily as the problem of how to optimally cut the fish and group the resulting portions. The literature review carried out for this purpose is presented in Sections 2.1 and 2.3. The filling operation is essentially mechanical in nature, and it involves the forming of fish portions into the desired can size and shape and the final filling itself. The literature relevant to the existing can filling machines and mechanism design is reviewed in Sections 2.1 and 2.2. And, finally, the post-filling task can be classified as a sensing and control problem, and it involves the detection and repair of defectively filled cans. The literature search conducted for this purpose can be found in Section 2.3. Also, the new design is examined for relative economic advantages when compared with the existing machines by carrying out a cost-benefit analysis. The relevant literature for this purpose is reviewed in Section 2.4.

Based on the foregoing discussion, the literature search done for this project can be classified into the following main categories:

- Can-filling machines and Automation,
- Mechanical design,
- Sensing and control requirements, and,
- Economic Evaluation.

In the following, important developments under each of these categories are given, which represent the state of the art. This will form the basis for the new designs that will be considered in the subsequent chapters.

### 2.1 Can-Filling Machines and Automation

An extensive literature search has been done to compile information about existing can-filling machinery. Of particular significance is the information gathered from the filling machine manufacturers located throughout the world. Information from the companies like PRC Inc.[6], Carruthers [7], and American National Can Company [8] has been particularly useful in understanding the can-filling process, and in arriving at new design concepts and industrial procedures. The PRC filler, shown in Figure 2.1, uses a pneumatic pump for feeding the portions into the filler unit. Fillings speed of up to 1400 cans per minute are achievable using this filler. The Carruthers filler (see Figure 2.2) which is used primarily for tuna canning, also uses a volumetric filling principle. The fill amount is controlled by filling a chamber of predetermined volume by compression. After the measuring chamber is full, the rotary unit located underneath is indexed so as to get the fill amount into the corresponding can. American Can Company's filler is the existing filling machine in question.

Patent literature also was surveyed. Some patents have been found useful for establishing the current state of technology with a view to developing improved machinery. Innovative filling and forming mechanisms are presented in US patents #4,116,600 [9] and #3,124,469 [10], respectively. Figure 2.3 (patent #4,116,600) shows an intermittent motion filling mechanism with fixed and movable half forming moulds. The fixed half moulds (13, 15) are attached to the rotary unit, which is composed of two concentric disks (11, 12). After the fish portions are fed at the filling station (18), the upper disk (11) is indexed through 90° and the lower disk indexed through 45°. A cut-off knife, located between the two disks, cuts the portions into two equal halves. Two movable half moulds (21, 25) then form the portions into

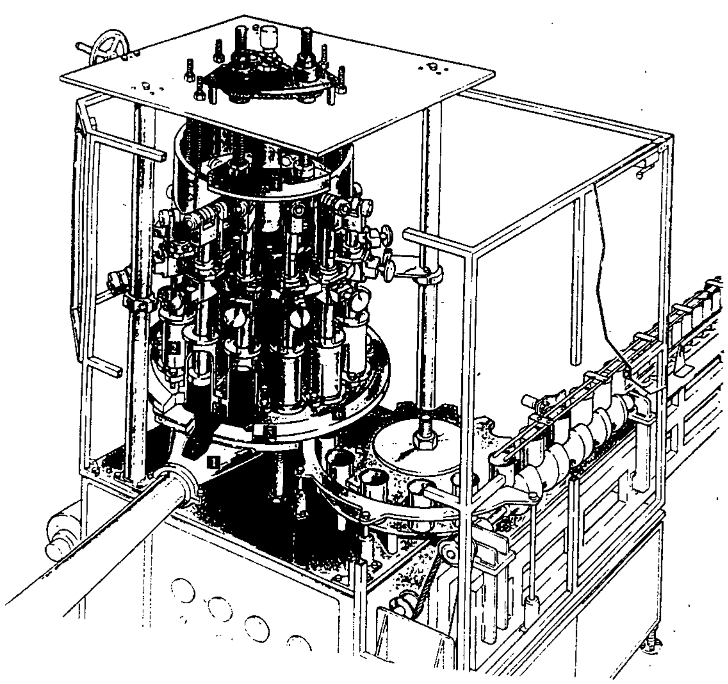


**Figure 2.1** PRC Filler.

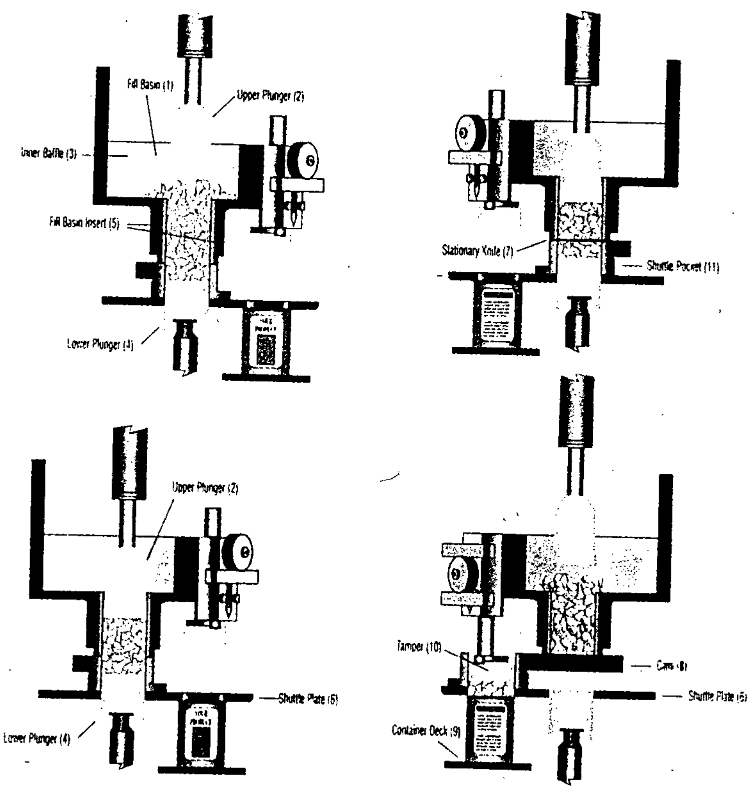



**Figure 2.2** Carruther's Nu-Pak Filler.

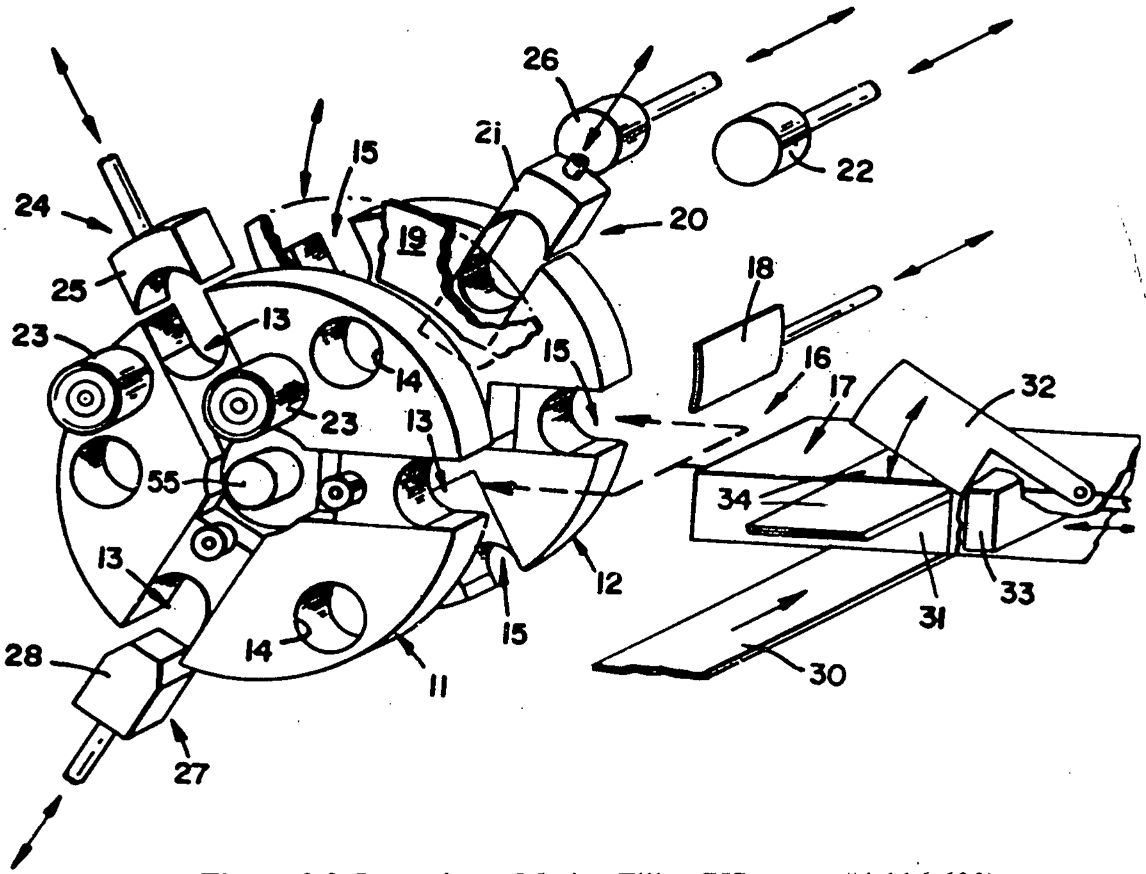



**Figure 2.3** Intermittent Motion Filler (US patent #4,116,600)

desired size and shape of the can, before the portions are pushed into corresponding cans (23) located underneath the rotary unit by means of plungers (22, 26). US patent # 3,124,469 [10] presents an innovative filling arrangement for solid pack tuna canning (Figure 2.4). The forming half moulds are made integral to the rotary unit and feed chain. The portions are formed and cut by squeezing action of the two half moulds as they approach each other. No forming plungers are used. US patent #3,874,426 [11] describes an innovative approach for fill weight control. It suggests that the filling operation be carried out in two stages. The cans are filled slightly underweight in the first stage. A small compensation amount is then added later in the secondary filling arrangement. Thus, better fill weight control is achieved by cutting down the number of overweight cans.

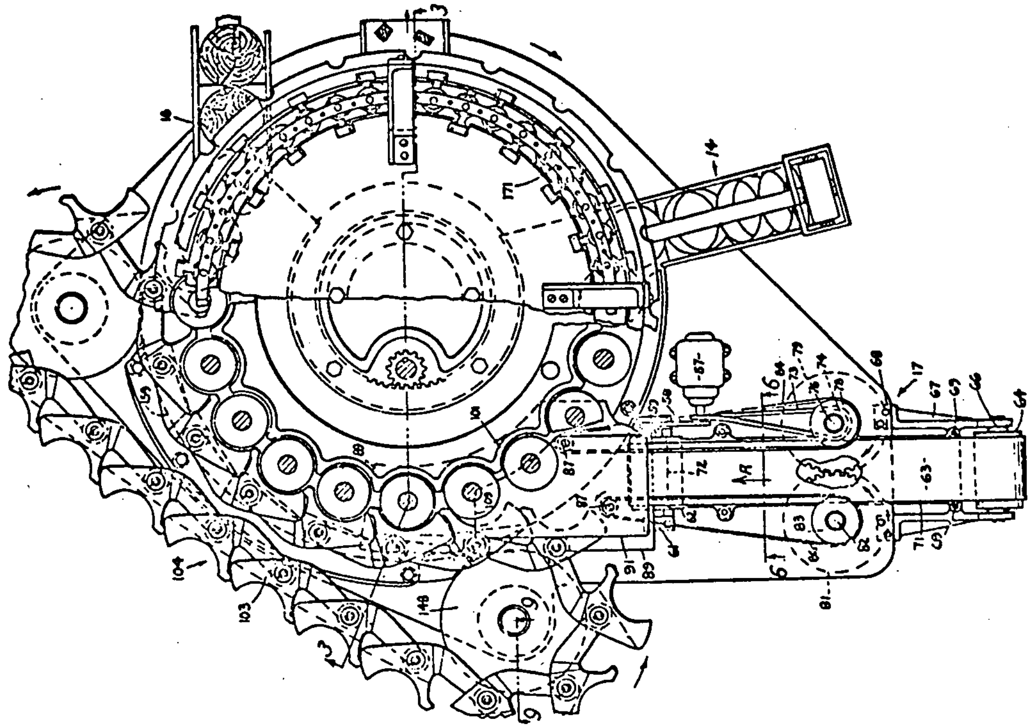


**Figure 2.4** Solid Pack Tuna Filler (US Patent #3,124,469)

Khodabandhaloo [12] cites many examples of the applications of robotics in the meat, fish and poultry processing. The use of machine vision for cutting and sorting of various meat products is of particular interest. Footitt [13] has reviewed the can-filling operations in fish-processing industry. De Silva [4, 5] has successfully employed machine vision and improved mechanical design and control of an automated machine to improve the performance of salmon head-cutting (pre-filling stage) operation. Work has also been done at the Industrial Automation Laboratory of the University of British Columbia, to automate the grading of herring roe using machine vision [14, 15]. This work demonstrates the potential for introducing intelligent sensory techniques in fish processing, and is being extended to the post-filling (inspection) operations in the can-filling project.

## 2.2 Mechanical Design

The scope of this project is limited to the design and development [16] of an automated can-filling system for fish with the main focus on the filling operations. The problem is mechanical in nature, and can be subdivided into three main tasks; namely, feeding, forming, and filling. As the name implies, feeding involves the conveying of fish portion(s) from the cutting and sorting unit to the filler. The information about various material handling conveyor systems is presented in [17] and [18]. The performance of a machine, to a large extent, is determined by the mechanisms that constitute it. The design and development of many innovative mechanisms are treated in [19] and [20]. Pneumatic and hydraulic actuators are increasingly being used in the packaging industry, these days. Various fluid power actuators are described in [21].

## 2.3 Sensing and Control Requirement

As explained in the subsequent chapters, the design and implementation of an automated filler unit may require a variety of sensing and control devices such as CCD cameras, proximity sensors, and load sensors [22]. Riahi and de Silva [23] have successfully used a CCD camera for detecting the location of a gill along the fish length. Subsequently, this information was used by Gamage and de Silva [24] to optimally cut the fish along a contour at the gill position. Portion control in the can filling application may incorporate similar technology. There are reliability issues which have to be addressed, and various alarms and safety devices that must be incorporated into the design. For example, the machine should carry out the forming and filling tasks only when both can and the matching portions are present. The presence of the cans beneath the rotary unit could be easily detected by using either proximity sensors or load sensors [22]. The load sensors could also help in keeping track of the weight of each can after the filling is accomplished. In addition they could assist in ensuring that the cans are in optimal contact with the top plate of the rotary unit. The actuation of the forming and filling actuators may be controlled by a simple sequential logic circuit [25].

### 2.4 Economic Evaluation

Cost-benefit analysis [26] and rate of return analysis are two commonly used techniques for justifying the replacement or addition of new machinery. Cost-benefit analysis has been done to find out the relative cost advantage of the proposed design. Information necessary for the evaluation has been gathered from diverse sources, like newspapers, government newsletters [3], and internal industry reports.

# Chapter 3

## Development of an Automated System for Can Filling

As discussed in Chapter 1, the existing can-filling machinery suffers from many drawbacks. These include: low filling speed, excessive wastage, poor product quality and filling accuracy, lack of versatility, and lack of feedback-control type automation. An improved design should eliminate or at least reduce most of these shortcomings, and in addition, it should also satisfy the current industry requirements, specifically higher operating speed, better filling accuracy, reduced wastage, versatility and a higher level of automation. This chapter describes the various intermediate steps involved in arriving at the final design for an automated can filling system for fish. Various design considerations to be addressed in the new design will be described in the next section. The design approach used in arriving at the new design will be presented in section 3.2. Different conceptual design ideas will be described in section 3.3. Finally, in section 3.4, these conceptual designs will be analyzed in order to select an appropriate design.

### 3.1 Design Considerations

After consulting industrial representatives and by considering the available information, it was determined that the new design should meet the following design requirements:

1 **Filling Speed**

The new machine should be capable of filling up to 500 cans per minute, which is almost double of what is possible with the existing machinery. Insufficient storage space and perishable nature of salmon are the major factors behind this requirement. Furthermore, it has been observed that in the existing machinery, the filling accuracy and the life of the sliding parts (e.g., cam rollers) are adversely affected by any increase of the operating speed. The new design should take into consideration all such problems.

2. **Filling Accuracy**

Filling accuracy is judged both quantitatively and qualitatively. Quantitatively, it means better weight control. The standard deviation of the net weight of filled cans should correspond to not greater than 1.5 grams for 1/4 lb, 2 grams for 1/2 lb and 3 grams for 1 lb cans. Qualitatively, it refers to the presentation and aesthetic appeal. Specifically, there should be no cross packs (i.e., skin on top) or skin and bones protruding on the top of the flange of the can. The latter defect would also pose problems during the seaming operation. It is desired that the defect rate should be zero.

3. **Versatility or Flexibility**

Owing to the seasonal nature of the industry, the machines are in operation for only 2 to 3 months during an year. It is desired that the new machine be flexible or versatile, i.e., it should be capable of handling other products like various species of fish, vegetables, and other meat products. There should be a provision for handling both cannery dressed and skinless-boneless salmon. Also, a flexible machine should be able to fill cans of various shapes and sizes, e.g., 1/4 lb, 1/2 lb, 1 lb, etc. with minimum changeover time.

4. **Reliability and Safety**

Reliability and safety are important factors which have to be considered in the new design. The number of components should be minimal and they should be designed to operate reliably throughout their design life. Hardware and software redundancy may be required. Also, there should be a provision of alarms and safety devises; for instance, to guarantee no can - no fill operation. This means that if a can is not present, no product will be wasted in an attempt to fill the missing can. Furthermore, the new design should meet or exceed company and government regulations with respect to design and sanitation requirements.

5. **Ease of Operation and Maintenance**

The new machine should be user friendly, i.e., it should be easy to operate with minimum training. Various parts of the machine should be easily accessible for periodic cleaning and maintenance. Any settings and modifications that are needed for product changeover should be fast and simple.

## 3.2 Design Approach

As analyzed in Chapter 1, the principle of volumetric filling, on which the existing filling machines are based, has been found to be the root cause of many of the problems that are present in these machines. In order to determine possible design improvements, various types of mechanical filling operations were explored.

There are three types of filling principles that are in common use:

1 **Volumetric Filling**

In this type of filling arrangement, the fill amount is controlled by filling a chamber of predetermined volume either by gravity or by compression. This technique is better suited for filling liquids or homogenous solid products.

2 **Weight based Filling**

In this type of filling arrangement, the filling amount is controlled by weighing the filling portion or by appropriately combining pre-weighed sub-portions. This technique is better suited for filling inhomogenous and solid products (of different shapes and sizes) which are otherwise difficult to handle using techniques such as volumetric filling.

3. **Time based Filling**

The filling is accomplished by affecting a constant flow of the product, as the containers pass underneath the flow outlet at a predetermined rate. This technique is suitable for filling liquids or granular, homogenous, solid products.

When handling inhomogenous and delicate meat products like salmon, it becomes difficult to achieve the exact target weight using a volumetric filling arrangement. In theory, this technique would result in accurate fills of solid products if the product being canned is adequately pressed together so as to achieve a uniform product density throughout the filling chamber. However, in almost all the can-filling machines used in the fish canneries today, filling is accomplished based on this principle. It can be concluded that by switching from the principle of volumetric filling to weight-based portion control, many of the problems associated with the existing technology can be eliminated. Furthermore, the industrial requirements like higher throughput rate, versatility (flexibility), and various provisions for process automation, including sensing, control, alarms and safety devices can be met by improving upon the mechanical design of the machine. For the ease of analysis, it has been decided to divide the entire canning operation into three separate operations as shown in Figure 3.1; specifically,

1) Pre-Filling
2) Filling
3) Post-Filling.

The pre-filling operation involves the cutting of fish into portions of length equal to the height of the can less the required head clearance, sorting them into various weight categories, and then grouping them together to form the desired can-filling amount.

The filling operation involves the forming of fish portions into desired size and shape followed by placing the formed portion in the can.

The post-filling operation ensures that the quality of the product is consistent throughout. The operation can be divided into two sub tasks; specifically: defect detection and rectification. Any defective cans will be singled out in the detection stage, and send to the rectification unit for appropriate treatment before being transferred to the main line.

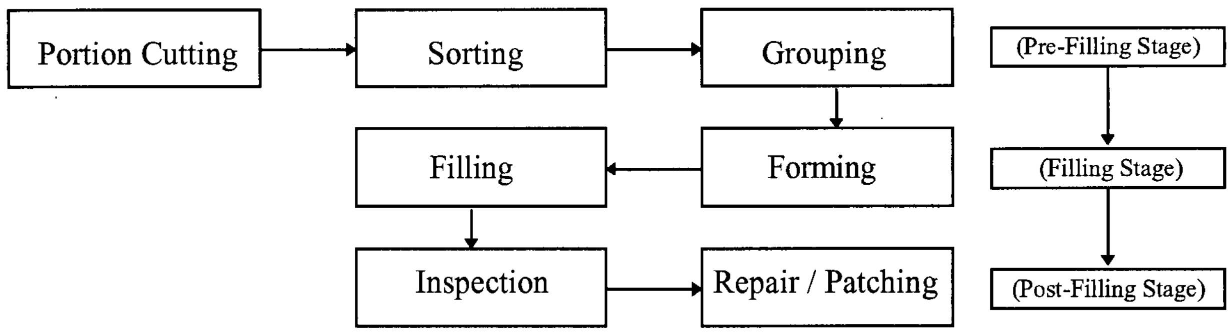



**Figure 3.1.** Proposed Can-filling Arrangement.

### 3.3 Conceptualization

After the canning problem had been decomposed into three separate functions; namely, pre-filling, filling and post-filling operations, the next logical step is to generate as many design concepts and procedures as possible for these functions. The following approaches have been utilized to generate these various concepts and procedures:

1. **Patents as an Idea Source**

About a dozen patents related to the can-filling machines and portion control have been examined in the course of the present research. This has enabled generation of some good ideas and design concepts. Although there are many patents related to tuna canning and vegetable/fruit canning, nothing specifically related to the salmon canning machinery has been found.

2. **Literature Search**

Various books and technical journals were examined to find out about existing designs, techniques and developments pertaining to the canning processes. Information was also obtained from various filling machine manufacturers located throughout the world.

3. **Knowledge of Experts**

Periodic meetings were held with filling machine experts, like Mr. Harold French, who has spent a major part of his life in the can-filling industry. A filling machine was acquired from industry and was taken apart to understand its components and details of various operations. Also, trips were made to various canneries in order to get acquainted with the can-filling process, machinery and associated problems.

4. **Brainstorming**

Brainstorming sessions were held at both individual and group level to generate multiple ideas. Periodic meetings were held for this purpose, primarily at our university laboratory.

Some of the conceptual design ideas generated for different functions of a can-filling process using the above approaches are presented in the remainder of this chapter.

### 3.3.1. Pre-Filling Operation

As shown in figure 3.1, the pre-filling operation can be further decomposed into three separate operations; namely, portion cutting, sorting and grouping. Portion cutting involves the cutting of cannery-dressed / skinless-boneless fish into portions, the size of which being dictated by the fill amount (volume and shape) and target weight for a particular can type. These portions are then sorted into various weight categories. And, finally they are grouped in an optimal manner so as to achieve proper can-filling amounts.

Four different concepts are presented below for the cutting operation.

**Concept 1**

A possible solution for portion cutting would be to use fixed gap cutters as in the case of existing machinery. Figure 3.2 shows one such arrangement. The distance between the adjacent the adjacent blades ($S$) is governed by the can height. Mathematically,

$S = H - C$

where,

$H$ = can height

$C$ = head space or clearance

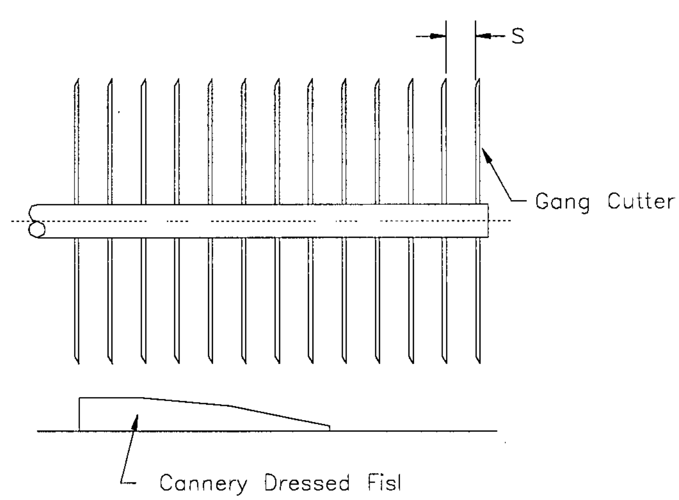



**Figure 3.2** Fixed-gap Cutter Arrangement.

The drawback of this arrangement is that it can not be used for filling cans of different sizes.

**Concept 2**

Another approach for cutting would be to use cutters with adjustable gaps. One such arrangement is shown in Figure 3.3. Pre-filling operation will involve, (1) cutting of cannery dressed fish into variable length portions of length equal to the height of a can less the required head space, (2) sorting these portions on the basis of their weight, and (3) regrouping them to form groups with the weight of each group falling within 90% to 100% of the target weight. The proper target weights can be achieved subsequently, during the filling process by adding pre-cut portions for weight compensation. Before being fed into the adjustable gang-knife cutter unit, each fish is imaged using a CCD camera. Then, depending on the grouping requirements, the cutter blades are adjusted to get portions of the desired size. The regrouped portions are then placed on a conveyor for carrying out further operations, including filling into cans.

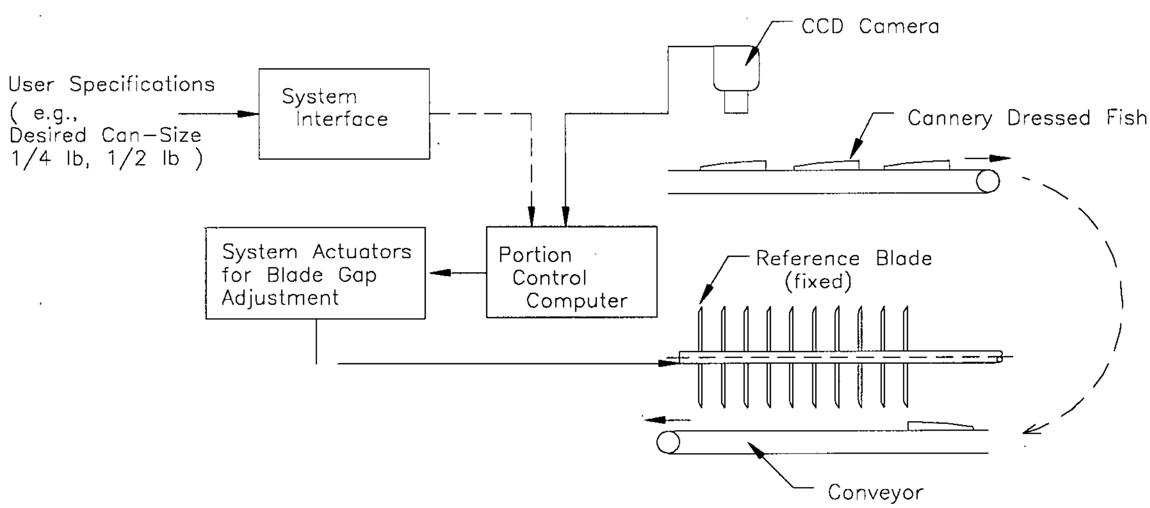



**Figure 3.3** Variable-gap Cutter Arrangement.

**Concept 3**

To facilitate the cutting process, the fish can be overlapped as shown in Figure 3.4. A CCD camera captures the image of each fish as it is passed onto Conveyor 1. The height of each fish is also captured using ultrasonic sensors. This information is then sent to a portion control computer, which determines the exact overlapping position for two adjacent fish, that would lead to somewhat uniform weight along the fish chain. A drum conveyor orients the fish by placing them on Conveyor 2 which moves intermittently. The speed of Conveyor 2 is controlled to achieve the desired overlap.

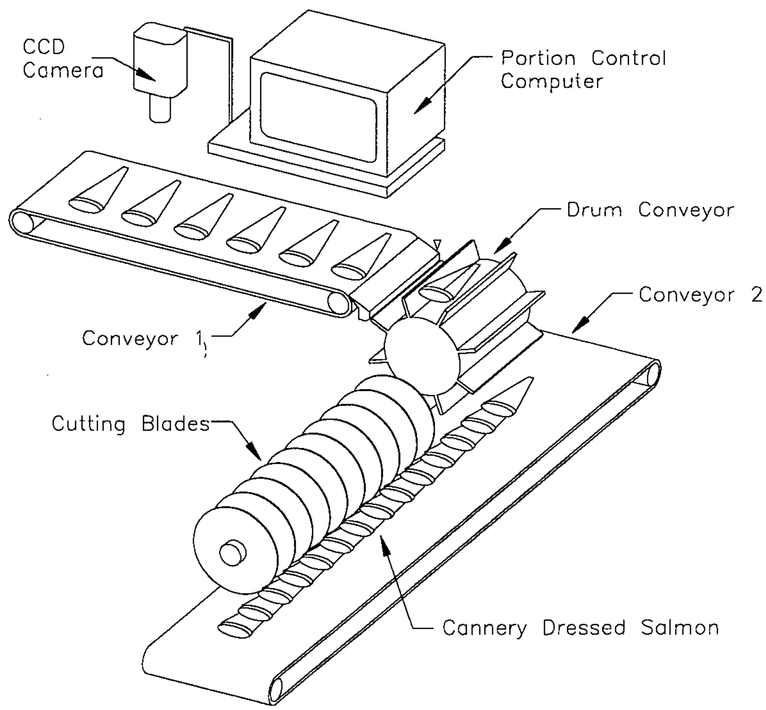



**Figure 3.4** Cutting Arrangement Employing Overlapped Fish.

**Concept 4**

Yet another approach that can be used with the volumetric filling arrangement would be to pack the fish into a tube of inside diameter that is equal to the can diameter. As shown in Figure 3.5, the fish are press-fed into the tube to make sure that the product density is somewhat uniform along the tube. A rotary cutter is used to cut the portion that goes into the can. One obvious drawback of this arrangement is that the excessive pressure exerted during the packing process would deteriorate the quality of meat, and squeeze out its valuable juices. This arrangement can not be used in high speed filling operations.

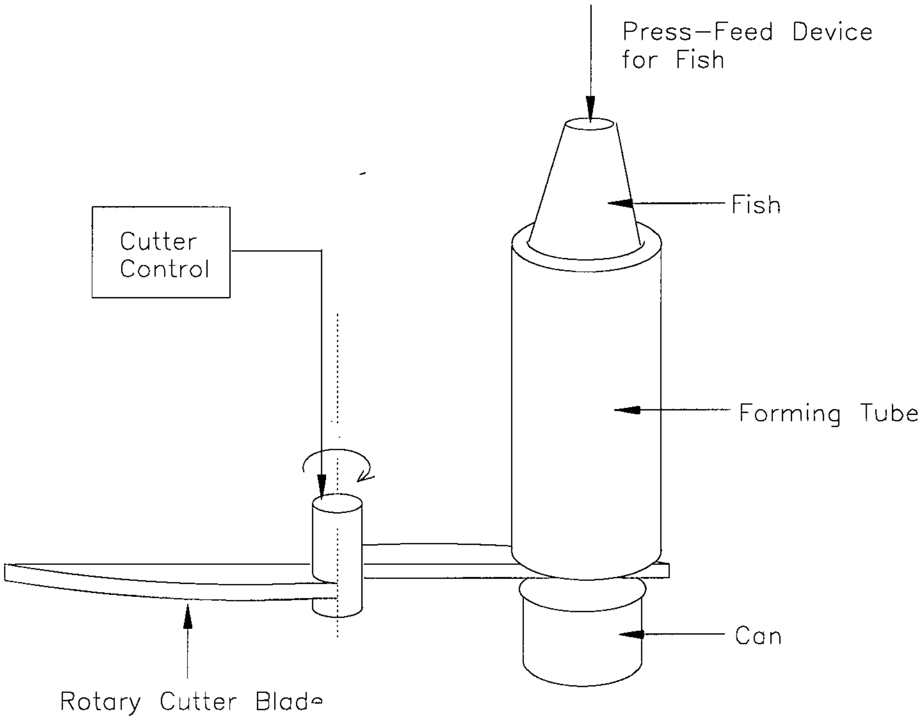



**Figure 3.5** Tubular Arrangement.

**<u>Concept 5</u>**

Since on-line mechanical weighing is not reliable at very high operating speeds, one approach would be to use machine vision for this purpose. This can be accomplished by developing a database of fish models, using static pictures as well as video tapes of fish [24]. The database would contain a set of models, each containing geometric dimensional measurements and weight for a representative class of fish. Since each model represents an entire class of fish, the data storage is economized, and the processing speed is improved. This would allow one to compare the image of an incoming fish with the models in the database, so as to obtain a match. The matched model is then used to estimate the true weight distribution of the imaged fish. This information could be subsequently utilized to cut the fish into portions of equal weight.

### 3.3.2 Filling Operation

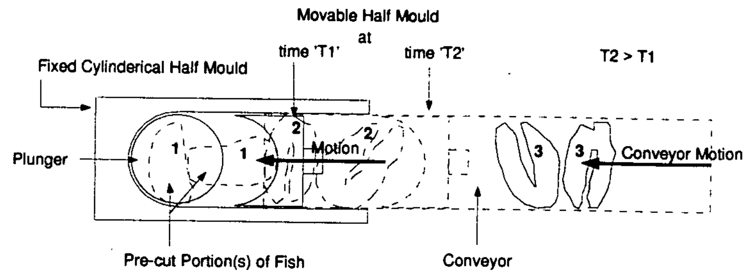
The filling operation involves forming the fish portions into the desired can shape and size, and the final filling itself. It is anticipated that the filler unit in the new design is supplied with the pre-weighed groups of fish portions instead of a continued flow of packed portions as in the case of volumetric filling used in existing machines. Consequently, the filler unit has to be radically different from the existing ones. At the same time, the design of the filler unit should take into account new requirements such as a filling speed of 500 cans/minute, handling of a variety of products and accommodating various shapes and sizes of containers. Furthermore, there should be a provision in the final design to compensate for grouped portions that are underweight. There should also be a provision for changing from one product to another or from one can size to another with minimal changeover time. These are requirements of increased flexibility of process operation. Many alternative design concepts are presented below to accomplish the filling operation in an improved design of can filling system.

**Concept 1**

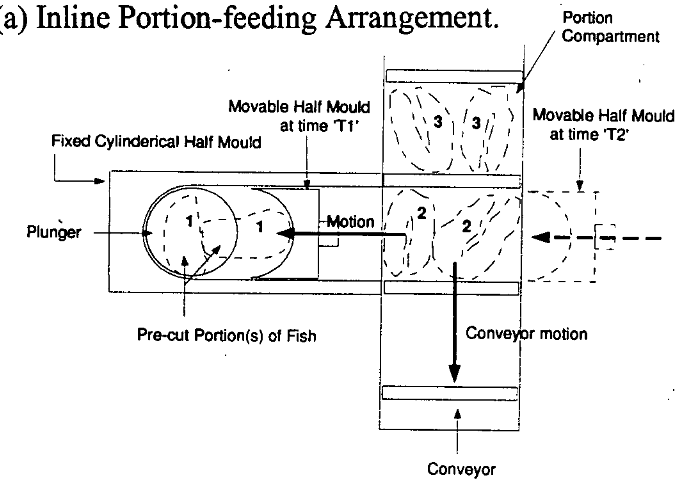
Figure 3.6(a) shows an arrangement for filling the pre-weighed portions into corresponding cans. The fixed and movable half molds are used to form (shape) the fish potion(s) into the desired shape. A plunger located above the fixed half mold pushes each formed portion into a can that passes underneath.

Due to the higher filling speed requirement (500 to 600 cans/minute), the pre-weighed portions are likely to be garbled up during the conveying process. Figure 3.6(b) shows an arrangement to avoid this problem. A compartmented conveyor with cleats or cross-flights would prevent the mixing up of the adjacent groups of fish portions.

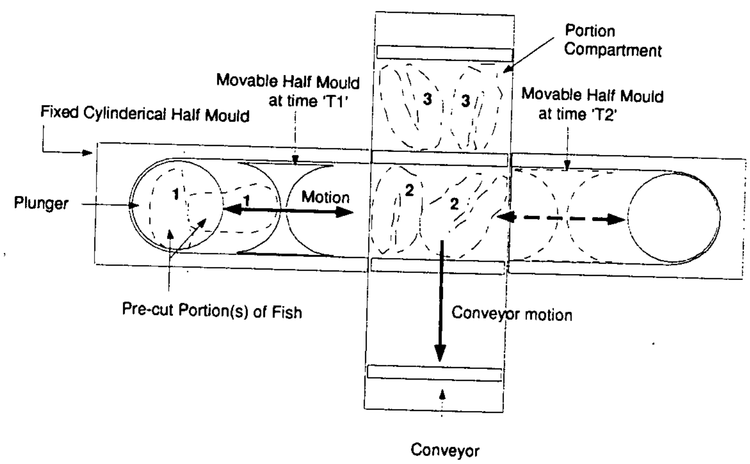
Figure 3.6(c) shows yet another arrangement, in which the advantage is taken of both forward and return strokes of the forming plunger (movable half mold). The filling speed for this arrangement would be theoretically double the filling speed in the previous case.




(a) Inline Portion-feeding Arrangement.




(b) Lateral Portion-feeding Arrangement.




(c) Double Acting Lateral Portion-feeding Arrangement.

**Figure 3.6** Alternative Filling Principles.

**Concept 2**

In this design concept, the cylindrical-shaped half moulds are formed on two separate elliptical trains. The elliptical shape is used to achieve sufficient contact time for the corresponding cylindrical half moulds on the two trains, thereby allowing the forming and filling operations to be carried out before the two mould halves disengage from each other. A conveyor, running at the same linear speed as that of the two elliptical trains, feeds the grouped fish portions into the filler unit. The adjacent portion groups are separated from each other by means of cross-flights or compartments built into the conveyor. One simple hardware configuration that could be implemented is shown in Figure 3.7. An advantage of this design is that the motion is continuous without any gaps or stops. The associated disadvantage is the difficulty of loading the portions onto a continuously moving conveyor.

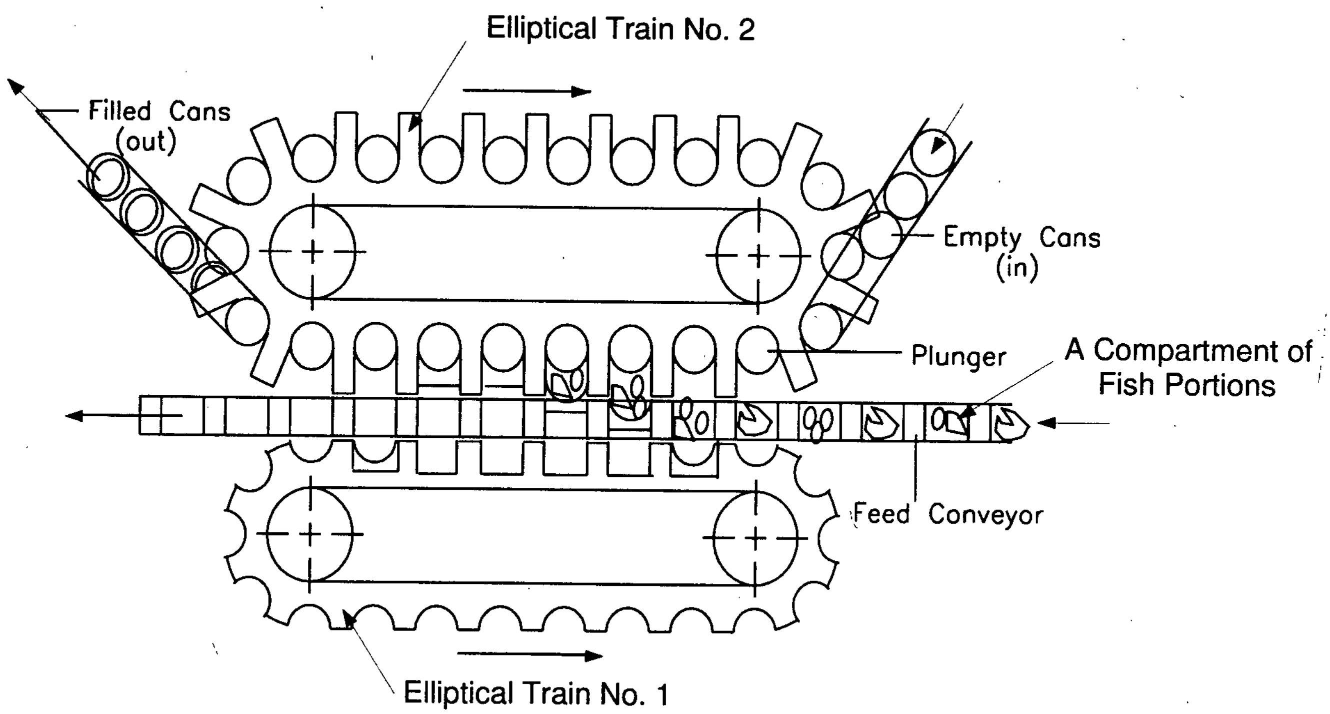



**Figure 3.7** An Elliptical Filler Concept.

## Concept 3

This design concept involves two rotary disks instead of the elliptical trains in the previous concept. The cylindrical half moulds, in this case, are carried by the arms attached to these rotary disks. The half moulds are mounted on their arms in such a way that, for a particular segment of rotation of the discs ( typically 30° to 45° ) these mould pairs are in contact with the corresponding compartment divider plates of the feeding conveyor and move at the same linear speed as the conveyor. A schematic drawing for this concept is shown in Figure 3.8. One disadvantage of this concept is the complexity of the mechanisms involved, and hence high cost. Also, in practice, with a uniform speed of rotation of the disks it would not be possible to accurately synchronize the linear speed of the mould segments with that of the feed conveyor.

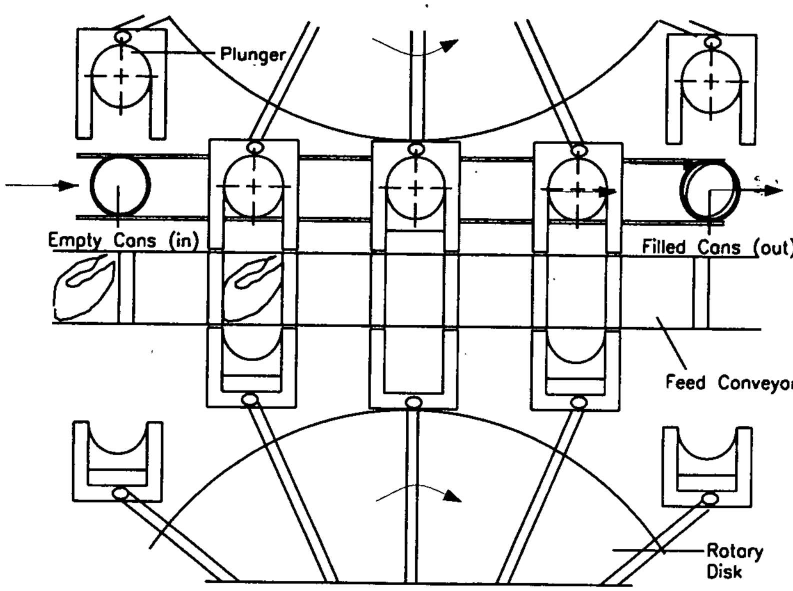



**Figure 3.8** A Rotary Filler Concept.

**Concept 4**

In this design concept, a chain conveyor with slates or compartments is used to transport the groups of fish portions to the filler pockets. The conveyor is driven by means of a sprocket built integral with the rotary filler, as shown in Figure 3.9. This common drive arrangement will make sure that the feed stations and the corresponding pockets in the filler are always accurately positioned with respect to each other.

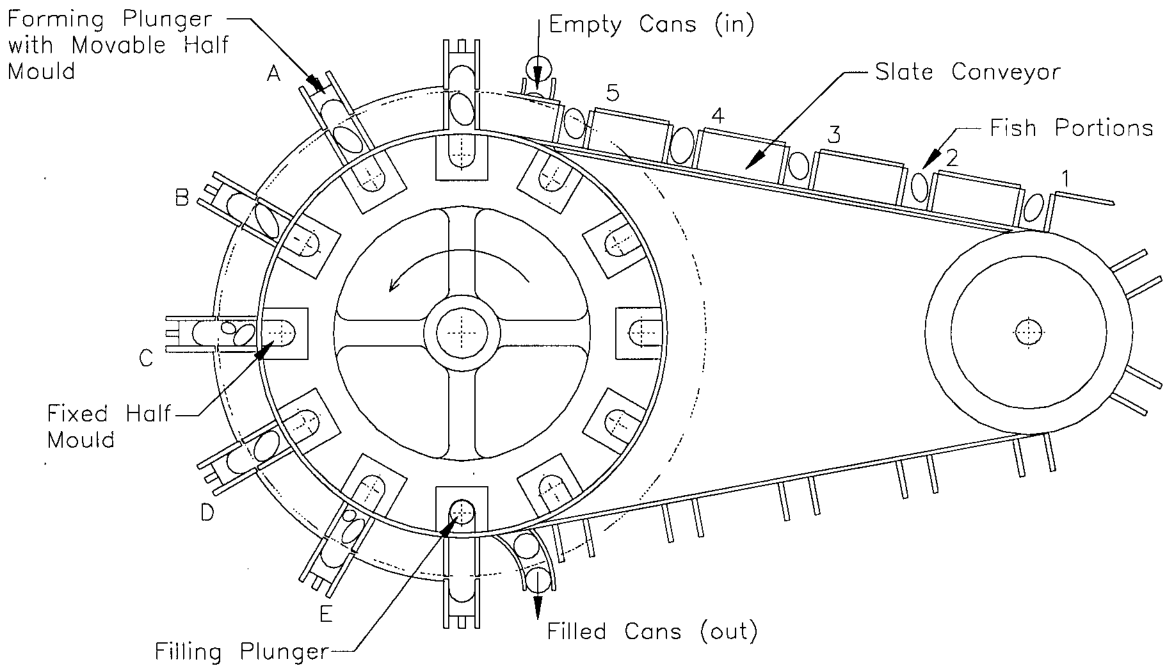



**Figure 3.9** A Rotary Concept with Slate Conveyor.

**Concept 5**

Figure 3.10 shows an arrangement for adjusting the canfilling amount depending upon the process requirements. This arrangement is actuated by a pneumatic or hydraulic actuator. Depending upon the height of the cans being filled and the physical conditions (e.g., density) of the fish being canned, the top dead center position of the plunger can be adjusted. The bottom dead center position is kept fixed and would serve as a reference. By incorporating this arrangement into the improved design of the filling machine, it would be possible to fill cans of different heights. For more sophisticated control, a pneumatic feedback servo could be used.

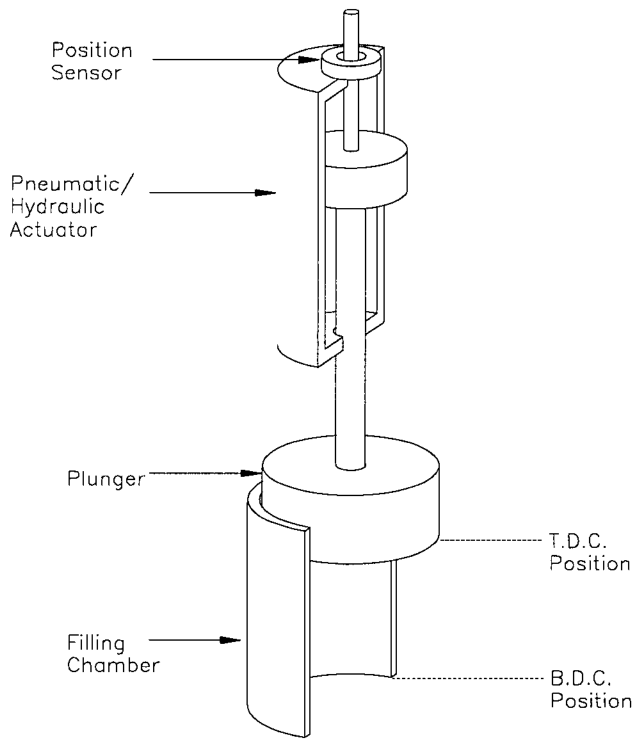



**Figure 3.10** A Mechanism for Filling of Variable Can Portions.

**Concept 6**

Figure 3.11 shows an arrangement for accommodating cans of different heights in the same filling machine. Pneumatic or hydraulic actuators are used in association with force sensors, to ensure that the cans are in tight contact with the top plate until after the filling has been carried out. This arrangement can also be used in conjunction with any other filler setup to accommodate cans of different heights. The purpose of the can lifting assemblies is to lift the cans against the top plate so that there is no product leakage during the filling process. The stroke of a lift-plate is adjusted depending on the height of the can it supports.

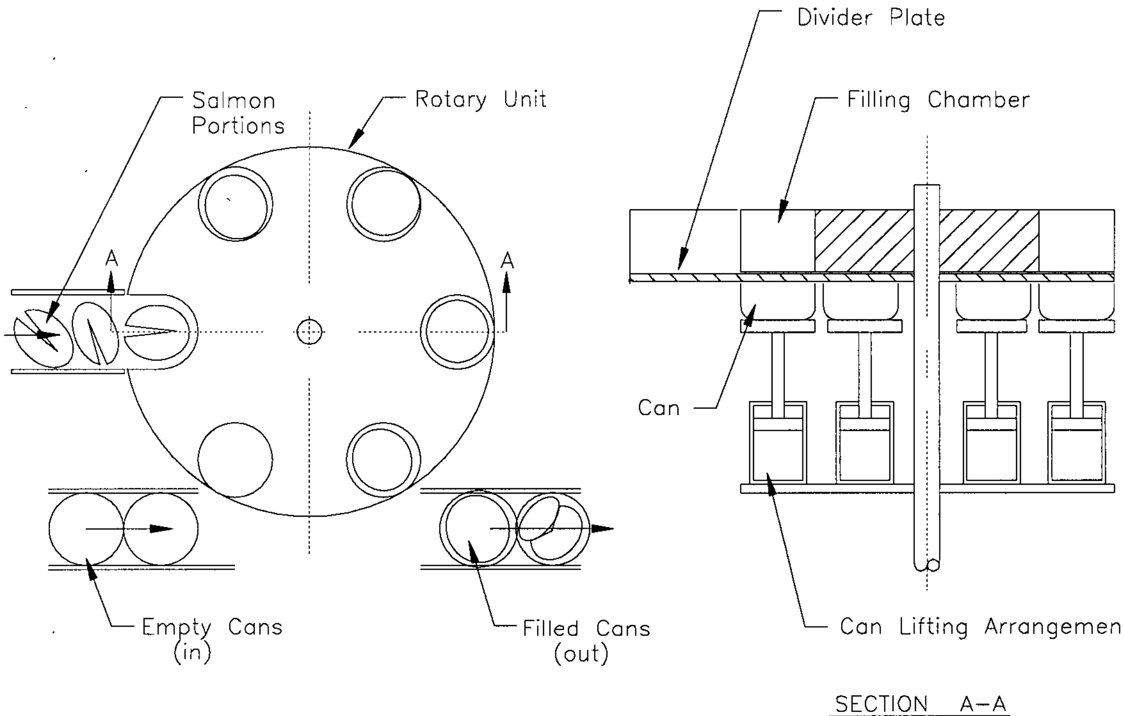



**Figure 3.11** A Mechanism to Accommodate Different Can Heights.

## Concept 7

Figure 3.12 shows an arrangement for accommodating different can shapes within the same filling machine. Both the fixed and movable half moulds are made detachable. Depending upon the cross-section of the cans being used, appropriate moulds are mounted in the respective locations. For ease of handling, the moulds are made of light weight plastic material. With such an arrangement, it would be possible to carry out the changeover (from one can type to another) in less then an hour. Different mould shapes are constructed in such a manner that the fill chamber cavity is always concentric with the filling plunger, when a mould is assembled. The concentricity (and hence interchangeability) is ensured by always making the mould cavity of assembled mould halves at same distance *R* from a reference mounting (locating ) position.

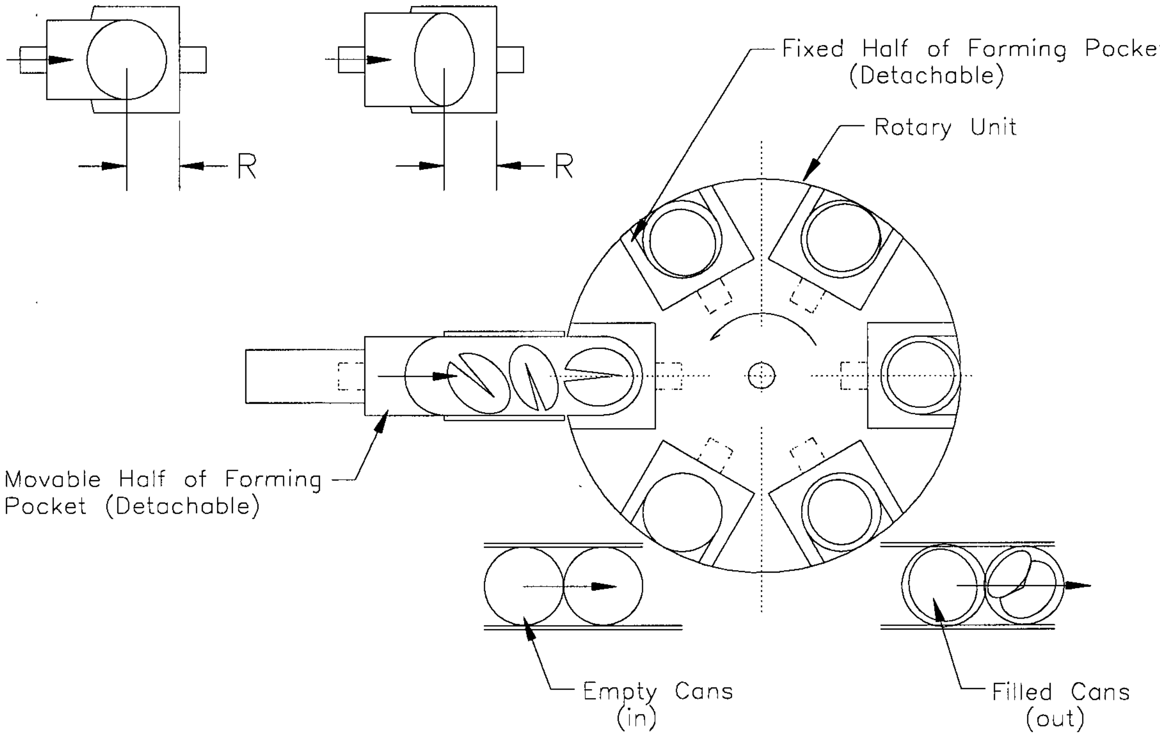



**Figure 3.12** A Mechanism to Accommodate Different Can Shapes.

**<u>Concept 8</u>**

Yet another approach would be to re-engineer the existing machine. This can be accomplished by using an adjustable cutter unit that will accommodate different sizes of cans. Other major improvements would involve a suitable replacement for the bucket conveyor, an improved feeding mechanism and a modified filler unit. The bucket conveyor used for conveying the portions into the twister tunnel is an expensive mechanism. The same function can be accomplished at a moderate cost by using a slate conveyor with cross-plates. Better weight control can be achieved by using separate drive systems for the tumbler fork and the rotary unit. Such a system would not allow the pockets of the rotary unit to advance until the measuring chamber is full. Another possible solution would be to use a load cell in the supply tunnel.

It has been found that in the existing machinery, the cam rollers wear out quite rapidly when the machine is made to run at speeds in excess of 250 cans per minute. This problem can be rectified by choosing better (wear-resistant materials) for the cam rollers, and by incorporating smoother and less radical transitions in the cam profiles. Furthermore, the elimination of extra weight of all moving parts by using composite materials or plastics would also aid in easing the wearout process. Figure 3.13 shows one such arrangement where the parts of the existing machinery have been re-engineered. The disadvantage of this arrangement is that, it relies on the same old principle of volumetric filling. Furthermore, since many radical changes are required, it would be an expensive option.

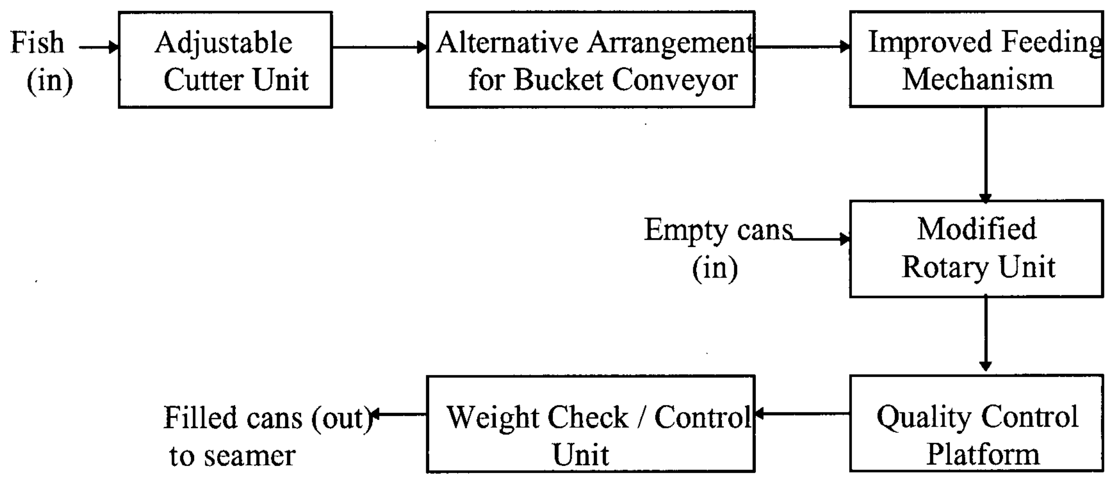



**Figure 3.13** Re-engineering of the Existing Machine.

### 3.3.3 Post-filling Operation

Once the filling operations are carried out, ideally there should be no underweight, overweight, or poorly filled cans. However, there is bound to be some deviation, especially when dealing with a variety of irregular shaped, non-homogenous objects like salmon steaks. In view of this, a provision for post filling operations of inspection and compensation for any defects in filled cans would be desired. The purpose of the post-filling operations is to check the quality of the end product for any deviations from what is desired, and if need be, rectify those defects. Several concepts that would accomplish the post-filling operations are described next.

**Concept 1**

Figure 3.14 shows an inspection / repair work cell. The filled cans are passed onto a visual inspection unit, where machine vision is used to detect cans with cross-packs (skin, bones on top), or those with skin and bones protruding on the flange. In addition, height sensors are used to check the problem of insufficient head-space. These defective cans as determined according to the required criteria, by using the sensory information, are then segregated onto an auxiliary line, where they are repaired in the visual-defect repair unit before being transferred back to the main line. The visually acceptable cans are then inspected for any weight defects. On-line weighing is used for this purpose. The underweight cans are passed onto an auxiliary line, where they are repaired in the weight-defect repair unit before being transferred back to the main line.

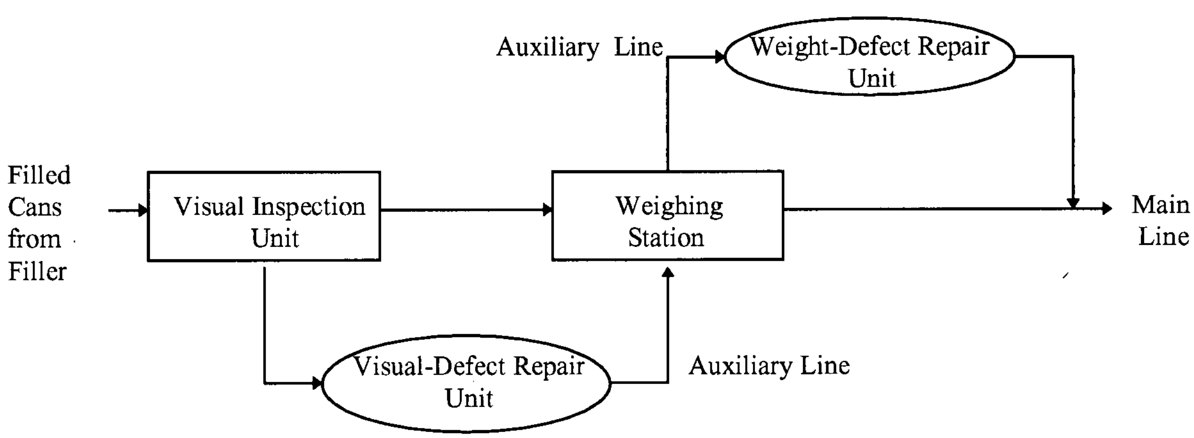



**Figure 3.14** Schematic Representation of an Inspection and Repair Line.

**Concept 2**

The government regulations limit the percentage of underweight cans that could be marketed by fish processing companies. To avoid any violations of this requirement, the general tendency on the part of the fish processing companies is to set the machines so as to fill the cans slightly overweight. To avoid overweight cans, an alternative approach could be employed. In this method, initially, all the cans are underfilled (slightly under the target weight), and then small compensation amounts are added through a secondary filling arrangement. The final amount of compensation, which would be in the form of a fine paste (slurry) of fish meat, can be injected using a fine nozzle as shown in Figure 3.15. The filling amount can also be controlled in this method by using a controller to adjust the stroke of the plunger. In fact, by keeping track of which portion group should be filled into which can, this compensation amount could be added just before carrying out the actual filling operation.

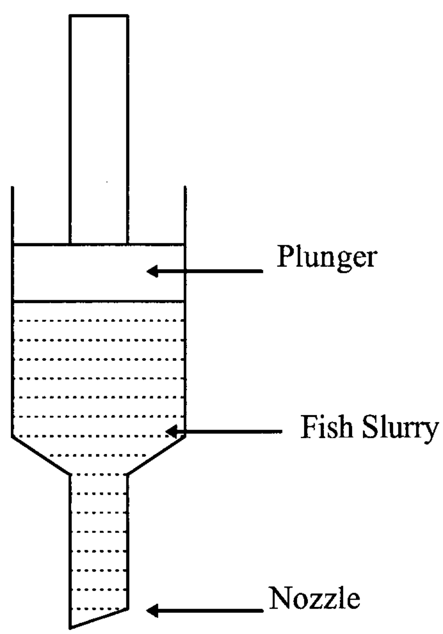



**Figure 3.15** A Weight Compensation Device.

### 3.4 Concept Evaluation

Once various conceptual solutions are generated, as outlined thus far, the next step would be to choose an appropriate set of concepts for development into the prototype stage. A decision matrix approach (Pugh's Method) [16] is used for this purpose.

The decision matrix approach is outlined now, in the context of the present problem. Since our problem is one of redesigning the existing can-filling machinery, the existing machinery, abstracted to the same level as the new concepts themselves can be used as the datum. For each comparison, the concept to be evaluated is judged as either better than , about the same as, or worse than the datum. If judged better than the datum, the concept is given a "+" score. If judged to be about the same as the datum or if there is some ambivalence, an S ("same") is used. If the concept does not meet the criteria as well as the datum does, it is given a "-" score.

After a concept is compared with the datum for each criterion, four scores are generated: the number of "+" scores, the number of "-" scores, the overall total, and the weighted total. The overall total is the difference between the number of plus scores and the number of minus scores. The weighted total is the sum of each score multiplied by an "importance" weighing. A score of S is given a numerical value 0, a "+" is given +1, and a "-" is given -1. The scores should not be treated as an absolute measure of the value of concept; they are intended for guidance only.

The above approach is used for choosing the best concept for the filler. The four concepts: (I) elliptical design, (II) rotary design, (III) re-engineering of the existing filler, and (IV) rotary design (with slate conveyor) have been compared, with the existing machinery serving as the datum. The comparison was made relative to our design requirements; specifically, filling speed and accuracy, initial cost, operation cost, ease of operation, throughput, versatility, reliability and feasibility. These requirements were ranked in order of importance on a scale from 1 (low) to 5 (high). The results of the comparison are summarized in Table 3.1.

**Table 3.1** Decision-matrix for the Filler.

| | Weight | I | II | III | IV | V |
|---|---|---|---|---|---|---|
| High Speed | 3 | + | + | + | + | D |
| High Accuracy | 4 | + | + | S | + | A |
| Low Initial Cost | 2 | S | - | - | S | T |
| Low Operating Cost | 4 | + | + | - | + | U |
| Simplicity of Operation | 3 | + | - | + | + | M |
| Low Wastage | 4 | + | + | S | + | |
| Versatility | 5 | + | + | - | + | |
| Reliability | 4 | + | + | S | + | |
| Feasibility | 5 | S | - | S | + | |
| Total + | | 7 | 6 | 2 | 8 | 0 |
| Total - | | 0 | 3 | 3 | 0 | 0 |
| Overall Total | | 7 | 3 | -1 | 8 | 0 |
| Weighted Total | | 27 | 14 | -5 | 32 | 0 |

Where

**I** Elliptical Filler Concept

**II** Rotary Filler Concept

**III** Re-engineering the Existing Machinery

**IV** Rotary Concept with Slate Conveyor

**V** Existing Machinery (DATUM)

On the basis of the decision matrix of Table 3.1, it is noted that the rotary filler (with slate conveyor) concept is clearly the best choice.

# Chapter 4

## Detailed Design of the Can Filling System

In the preceding chapters, a systematic approach was presented for selecting an appropriate conceptual design for the can filling system. The next step is to transform these concepts into actual product designs which can be evaluated and developed into prototype systems. Of major importance during this refinement process is the concurrent development of the can filling system and the procedures that will be used in its physical development, testing, and refinement. The concepts in Chapter 3 give no details about the final form of the filling machine. As the physical form of the system evolves, one must make decisions about the materials used in various physical components and the decisions as to how these components will be made. This chapter focuses on further refinement of the conceptual design. Sections 4.1 and 4.3 will briefly describe the pre-filling and post-filling stages, respectively. The filling stage will be developed in detail in Section 4.2. Next, Section 4.4 will describe the operation of the machine. And finally, design features and design limitations will be discussed in sections 4.5 and 4.6, respectively.

### 4.1 Pre-Filling Stage

As discussed in the previous chapter, the pre-filling operation can be further subdivided into three separate operations; namely, portion cutting, sorting and grouping. Portion cutting involves the cutting of cannery-dressed or skinless-boneless fish into portions, the size of which being dictated by the fill amount (both volume and shape) and the target weight for a particular can type. These portions are then sorted into various weight categories. And, finally they are grouped in a somewhat optimal manner so as to achieve proper can-filling portions.

The next two sections of this chapter will suggest some methods for cutting, sorting, and grouping of the portions that will realize this objective of portion control.

### 4.1.1 Cutting Methods

In the proposed design of portion control, even though the fish are cut by length along the body axis, the filling portions have to be necessarily grouped according to weight. For this approach to be effective, some information correlating weight to physical dimensions of a fish would be needed. Some work has been done to determine the length-weight correlation for salmon [27].

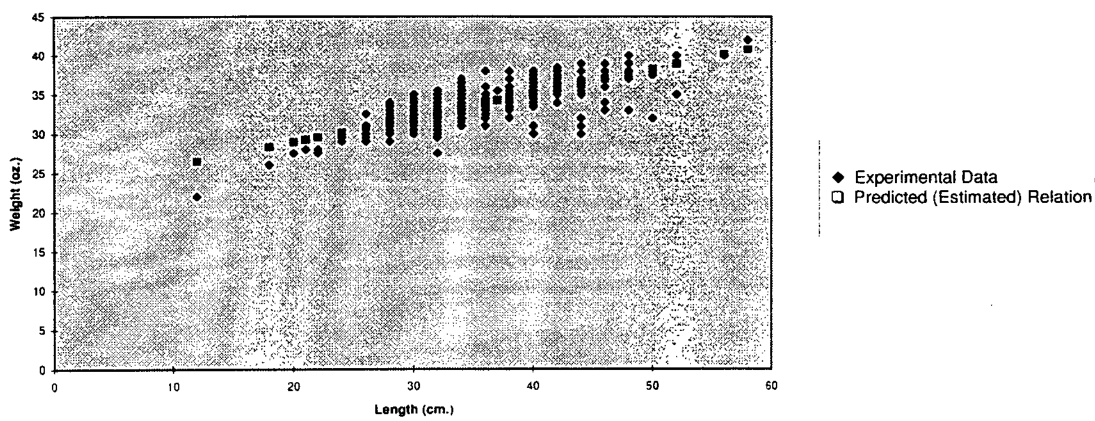



**Figure 4.1** Length-Weight Correlation for Pink Salmon.

Figure 4.1 shows such an experimental relationship for pink salmon, developed by us based on a sample size of 400 fish. Better results can be obtained by doing a multivariate regression analysis using length, width, thickness and weight of fish as the parameters of correlation. The data set used to generate the correlation shown in Figure 4.1 is given in Appendix A. Attempts have also been made at estimating the weight of fish by analyzing its two-dimensional image and the thickness profile. Since on-line mechanical weighing is not reliable at higher operating speeds, one obvious approach for accomplishing this would be to develop a database of fish models, using static pictures as well as video tapes of fish [24]. The database will contain a set of models each containing geometric, dimensional measurements and weight for a representative class of fish. Since each model represents an entire class of fish, the data storage is economized, and the processing speed is improved. This would allow one to compare the image of a fish that is to be processed, with the models in the database, so as to obtain a match. The matched model is then used to estimate the true weight distribution of the imaged fish. This information would be further utilized to cut the fish into either portions of equal weight or into portions which could be combined to give the required weight while satisfying some additional (e.g., size and shape) criteria.

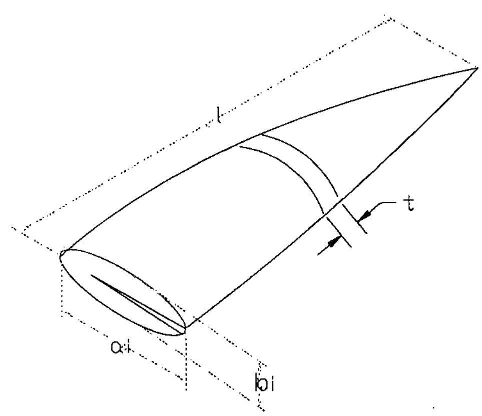



**Figure 4.2** Fish Dimensions for the Volumetric Portioning Approach.

Figure 4.2 shows yet another method of determining the weight of a fish. Cross-sectional profiles of the fish are captured successively along the fish length using line-scan cameras. Since the cross-section of fish along its length is somewhat elliptical, its weight can be determined as follows.

The volume of fish is,

$$V = \frac{\pi . t .}{4} \sum_{i=1}^{i=n} a_i . b_i \qquad (4.1)$$

where,

$t$ = the spacing between successive line scans,

$a_i$ = the horizontal span of the ith (major axis) scan,

$b_i$ = the vertical height of the ith (minor axis) scan, and

$n$ = the total number of scans.

Then the weight of fish is established as,

$$W = k.\rho.V, \tag{4.2}$$

where,

$k$ = a correction factor, and

$\rho$ = the weight density of the fish from a particular sample.

This same information may be utilized to cut a fish into equal weight portions. Specifically, the weight per unit length of fish at the scanning location $i$ along the body axis of fish is given by:

$$w_i = \frac{\pi}{4}.k.\rho.a_i.b_i. \tag{4.3}$$

This weight distribution profile is plotted for each fish, and then overlapped with an axial location delay so that the sum of the profiles would be somewhat uniform. The average of the summed profiles would give the weight distribution parameter $\bar{w}$ that is employed in portion cutting. In particular, if $W_p$ is the required weight of a cut portion, the average cut spacing (thickness) $\bar{t}$ is given by:

$$\bar{t} = \frac{W_p}{\bar{w}}. \tag{4.4}$$

Figure 4.3 illustrates, how this approach works. An experimental evaluation of this method is presented in Chapter 6.

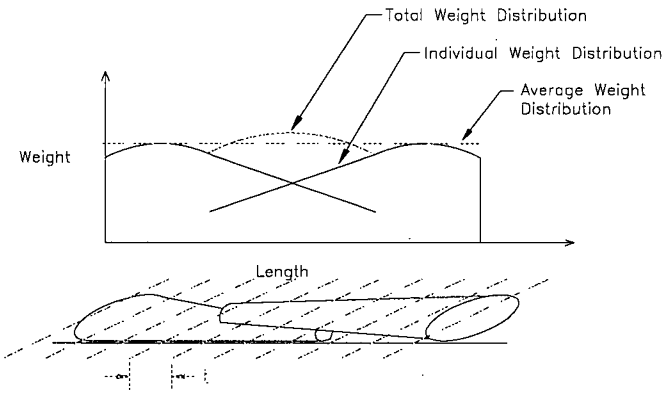



**Figure 4.3** Overlapping of Fish to Achieve a Uniform Weight Distribution.

As described in Chapter 3, an adjustable-gap cutter arrangement may be employed to vary the can-filling amount for various sizes of cans.

### 4.1.2 A Sorting and Grouping Method

A sorting and regrouping method for fish portions is presented here that would achieve groups of fish portions whose combined weight approximates the exact can-filling (target) weight. It should be noted, however, that the actual weight of the portion groups is kept slightly under the target weight (typically 90%-100%), so as to ensure good weight control through a subsequent secondary fine filling operation. This would also make sure that the filling process is carried out smoothly without undesirable delay while waiting for perfectly matching portions. The problem can be formulated as a linear programming problem. The objective is to match the pre-cut, and pre-weighed portions in a rather optimal way, such that their weights fall within some percentage of the target weight (typically 90%). The problem is formulated next.

Suppose that a fish has been cut into $n$ portions, such that the axial length of each portion equals the can height, allowing for some clearance. Now, suppose that the second fish yields $m$ portions. The problem can now be formulated as a linear-programming assignment problem, where the portions from the first fish serve as the destination point, and the portions from the second fish serve as the source point. The objective is to optimally assign (group) the portions from the source to the destination such that the weight of the individual groups thus formed falls within 90% of the target weight. For this algorithm to work, the number of source locations must always be equal to the number of destination locations. This can be achieved by including one or more dummy locations at the source or destination. The number of dummy locations is found by taking the absolute value of the difference between $n$ and $m$. Depending upon whether $n > m$ or $n < m$, the dummy locations would be added either to the source or to the destination. The linear programming model is now as follows:

The objective is to minimize

$$Z = \sum_{j=1}^{j=k} a_{ij}x_{ij}, \text{ for all } i = 1, 2, 3, \ldots\ldots\ldots, k, \tag{4.5}$$

under the constraints:

$$\sum_{j=1}^{j=k} x_{ij} = 1, \text{ for all } i = 1, 2, 3, \ldots\ldots\ldots, k. \tag{4.6}$$

Here the variables $x_{ij}$ can take only the binary values, 0 and 1. Also,

$k$ = maximum ($n$, $m$). (4.7)

$a_{ij}$ = weight deviation factor associated with grouping a portion from $i$th source location with a portion at $j$th destination location, which is determined by the value of $[W_t - ({}^{s}w_i + {}^{d}w_j)]$. (4.8)

$W_t$ = target weight for a particular can type.

${}^{s}w_i$ = weight of portion at $i$th (source) location.

${}^{d}w_j$ = weight of portion at $j$th (destination) location

Note that $x_{ij} = 1$, if and only if the $i$th source portion is grouped with the $j$th destination portion, and $0.1 \times W_t \geq [W_t - ({}^{s}w_i + {}^{d}w_j)] \geq 0$.

The problem as formulated above can easily be solved by using commercially available linear programming software, and a control interface can also be made with the software to actuate the grouping mechanism. Figure 4.4 shows an arrangement for accomplishing this task.

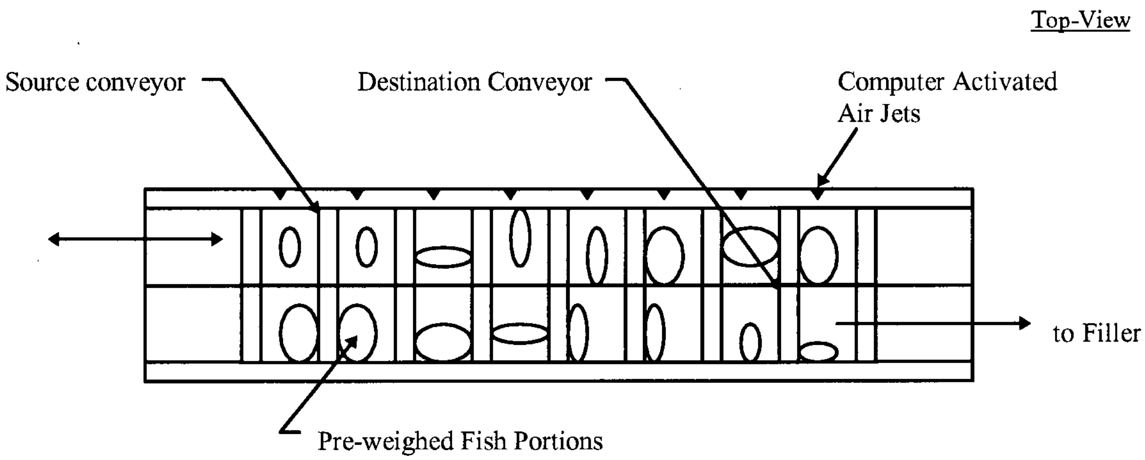



**Figure 4.4** An Optimal Grouping Arrangement.

As shown in the figure, the portions from the source conveyor are matched with the ones on the destination conveyor. The speed and direction of motion of the source conveyor are controlled by a computer using the grouping algorithm so that each portion of fish on it is added to the matched portion on the destination conveyor, say by using an air jet. The destination conveyor feeds the filler.

## 4.2 Filling Stage

As described in Chapter 3, the filling operation involves forming of the fish portions into the desired can shape and size, and the final filling itself. Since the filler unit in the new design is supplied with the pre-weighed portion groups instead of a continued flow of pressed portions as in the case of volumetric filling used in existing machines, the filler unit has to be radically different from the existing ones. At the same time, the new design should satisfy the following industrial requirements:

- It should be capable of filling at the rate of 500 cans per minute or higher.
- It should meet or exceed all company and government regulations with respect to weight control and defect rates. The standard deviation should not be greater than 1.5 grams for 1/4 lb cans, 2 grams for 1/2 lb cans, and 3 grams for 1 lb cans. The defect rate should be practically zero, i.e., there should not be any cans with skin / bones at the top or with the skin / bones protruding onto the flanges.
- It should be capable of processing both cannery dressed fish and fillets for the skinless and boneless pack, with the required change over time not exceeding one day.
- it should be user friendly and adaptable to quick (less than one hour) changes in operating parameters based on market requirements. This would include changes of target weights, and cans of various shapes.
- It should properly operate under various processing environments (humidity, temperature, lighting, vibration etc.) and in any desired location.
- It should meet or exceed all company and government regulations with respect to design and sanitation requirements.

### 4.2.1 Mechanical Design of the Filler Unit

In the previous chapter, the rotary filler with a slate (compartmentalized) conveyor was judged as an appropriate conceptual design for the filler system. This concept is further examined and developed next.

#### 4.2.1.1 General Layout

With the objective of finalizing the design, it would be appropriate to first understand the workings of the proposed concept of filling. An outline of the proposed filler mechanism is shown in Figure 4.5. The pre-cut and pre-weighed portions are fed to the slate conveyor at the five feed stations numbered 1, 2, 3, 4 and 5. The separating plates mounted on the slate conveyor prevent mixing of the pre-weighed portions among different groups. After the portions have been fed, the rotary unit is indexed through five pockets. The conveyor is driven by a sprocket mounted on the rotary unit such that the fish portions are automatically positioned in front of the respective filler pockets. Next, the forming plungers (movable halves of moulds), located facing the corresponding filler pockets (fixed halves of moulds) and aligned with the fish compartments of the conveyor, will push these portion groups into the fixed half moulds attached to the rotor. The fish portions are formed into the desired can-shape through the mould movement in this manner. The separating plate located underneath the rotor has openings for the formed portions to be pushed into the cans. Before the plungers (mounted on the rotary unit) push these portions into the cans located underneath the filler pockets, the separating plate is indexed so as to expose the formed fish portions to the corresponding cans. During the process, the portion groups of fish are successively fed to the empty compartments of slate conveyor at the five filling stations. This whole process is continued to fill the required number of cans. One obvious advantage of this concept is the simplicity of operation. Also, since the feed conveyor is directly driven by the rotary filler unit, the portions are always positioned in front of the respective pockets.

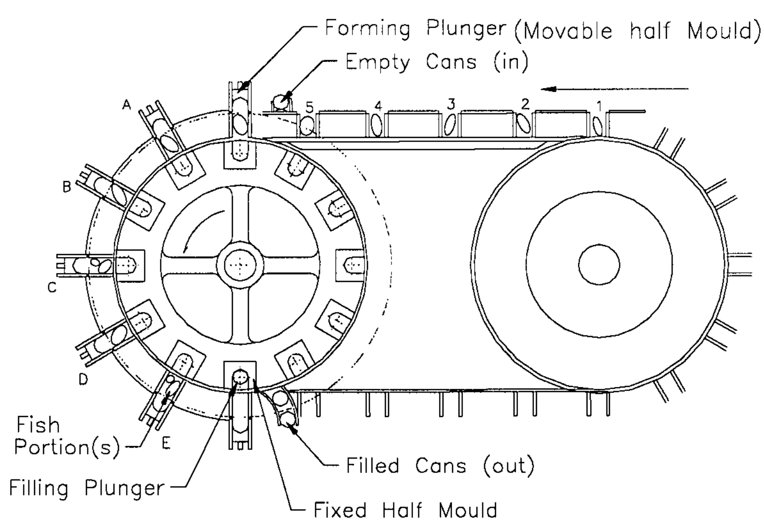



**Figure 4.5** Layout of the Proposed Filler Mechanism.

The first step in the development of the design would be to establish the dimensions and material requirements for the main components of the machine. The filling chamber is one major component of the machine. Since the machine is expected to handle a variety of can sizes and shapes, the filling chamber is designed as discussed below.

**Table 4.1** Can Types Commonly Used in the Fish Processing Industry.

| Can Size ($inch^2/10^4$) | 301 × 106* | 307 × 115 | 307 × 113.5 | 307 × 111 | 301 × 408 |
|---|---|---|---|---|---|
| Can Style | 2 piece | 2 piece | 2 piece | 2 piece | 2 piece, taper |
| Nominal Net Weight (gm) | 106 | 213 | 213 | 184 | 418 |
| Standard Tare Weight, Open Top Can (gm) | 22 | 32 | 26 | 25 | 55 |
| Standard Tare Weight, Can Plus End (gm) | 33 | 46 | 40 | 39 | 66 |
| Patching Table Weight (gm) | 128 | 245 | 239 | - | 473 |
| End of Line Weight (gm) | 140 | 260 | 254 | 224 | 485 |
| Weighing Machine Weight, Heavy** (gm) | - | 207 | 207 | - | 408 |
| Weighing Machine Weight, Light *** (gm) | - | 204 | 204 | - | 405 |

* $301 \times 106 \equiv 3\frac{1}{16}'' \times 1\frac{6}{16}''$.

** nominal net weight - (1 x permitted tolerance).

***weighing machine weight, light + 3 gm.

Table 4.1 lists the some useful information about various can-types used in the fish processing industry today. It can be seen that the cans come in fixed diameter of approximately 3 inches (3.0625" - 3.4375"), whereas a variety of can heights ranging from 1.375 inches to 4.5 inches are available. Based on the above information, the dimensions of the detachable half mould are set as shown in Figure 4.6. The distance between the inside walls of the mould $d_i$ is governed by the diameter of the incoming cans, and is calculated as follows:

$$d_i = D_c - K \tag{4.9}$$

where,

$D_c$ = can diameter,

$K$ = 0.02 to 0.03 inch clearance on the can radius.

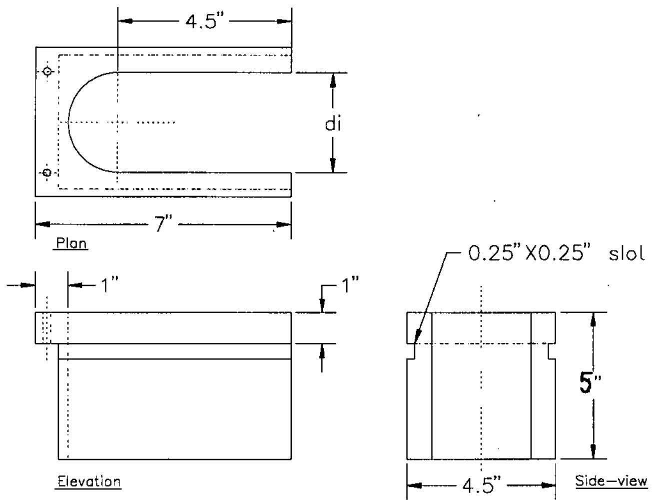



**Figure 4.6** Fixed Half Forming Mould.

The fixed half mould carries half of the inside profile of a can. In order to facilitate accurate positioning of the mould with respect to the filling plunger on top and the cans underneath, rectangular grooves have been cut on the three sides of the mould which fit onto the corresponding rectangular projections machined in the rotary unit. Once a mould has been mounted onto its rotary unit seat, guide pins are used to secure it to the rotor. These pins also make sure that the mould properly mounts.

The movable half mould carries the other half of the inside profile of a can, and is also detachable. Figure 4.7 shows the various dimensional features of the mould. The mould is secured to the actuator shaft by means of a bracket as shown in the figure. A forming plunger is used to form the fish portions into the desired can shape after transferring them from the slate conveyor to the fixed half moulds located in the rotary unit. Figure 4.8 shows how the slates are mounted on the chain conveyor. The distance between the inside walls of two adjacent slates is governed by the diameter of the cans to be filled, and can be calculated by using equation (4.9). The filling plunger has internal threads on it (See Figure 4.9), and is mounted onto a threaded piston rod.

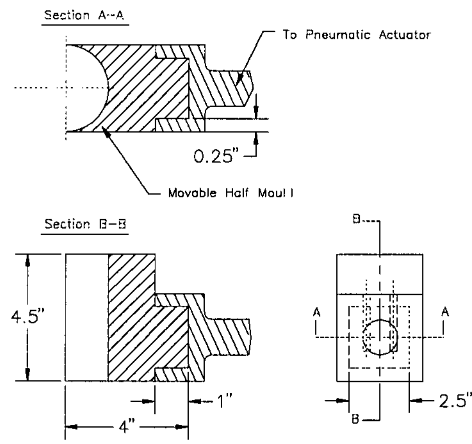



**Figure 4.7** The Movable-Half Forming Mould.

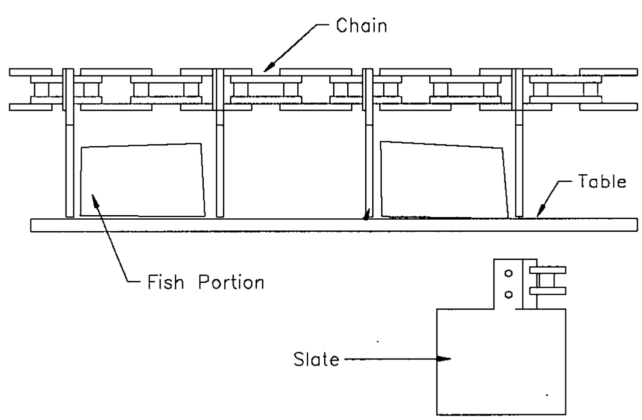



**Figure 4.8** A Chain Conveyor and Slated Mounted on It.

As the machine is required to carry out can filling at a rate of 500 cans per minute (8.33 cans/second), the minimum speed of the slate conveyor can be calculated as indicated below.

Width of a can = 3 inches , approximately

Filing speed = 500 cans/minute,

= 8.33 cans/second.

This means one can is filled in approximately 0.12 seconds. Therefore, assuming that there are no gaps in the filling process, the minimum conveyor speed = 3 inches/0.12 seconds = 25 inches/second.

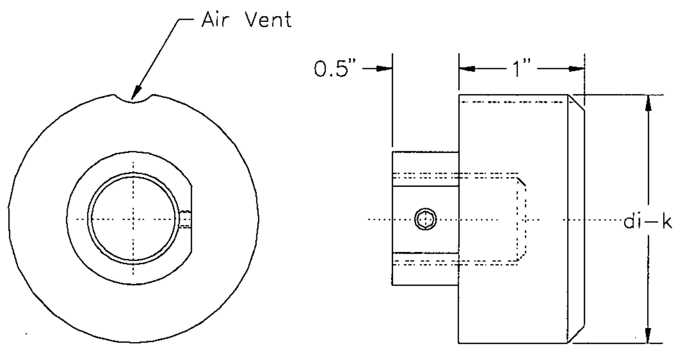



**Figure 4.9** Detachable Plunger (Thread-Mounted).

At such a high speed, it becomes difficult to place the portions in the respective compartments in the slate conveyor. The problem is more serious than that, since the portions have to be placed on the conveyor in vertical orientation to insure a good quality fill. For these reasons, it has been decided to perform the filling operations in an intermittent manner. To prevent any undue delays incurred in frequent starting and stopping of the machine, it has been decided to incorporate a rotary unit with a large number of filling stations. Rotary units with 60 or more filling stations are available in the market. Taking into account various design considerations; e.g., physical dimensions, speed and power requirements, it has been decided to equip the rotary unit with 42 stations @ 6.00" pitch (at the periphery). The key dimensions of the rotary unit can be determined as follows:

Rotary unit diameter, $D_{ro} = \dfrac{42 \times 6}{\pi} = 80.21$ inches

Rotary unit Height, $H_r = H_c + C_s = 4.5 + 1.5 = 6.0$ inches

where,

$H_c$ = maximum can height

$C_s$ = clearance for the sprocket.

Based on the rotary unit size, the dimensions of the can starwheel can be determined. The can starwheel is a wheel used for precise positioning of the cans under the respective filling stations. The main dimensions of the rotary unit and the can starwheel are shown in the figures 4.10 and 4.11, respectively. After entering the filler, the cans are always in contact with the top plate shown in Figure 4.12. To facilitate the changeover from one can diameter to another, the top plate is made into two halves. During the forming operation, the portions are supported by the divider plate, shown in Figure 4.13. After the forming operation, the divider plate is indexed between the guide rails to allow the formed fish portions to be pushed down into cans underneath the top plate.

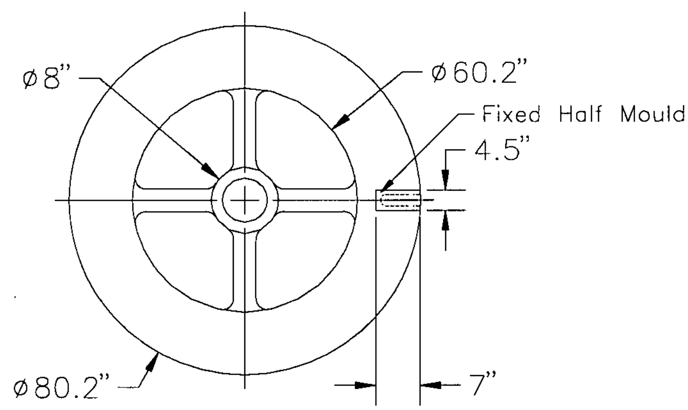



**Figure 4.10** Rotary Unit.

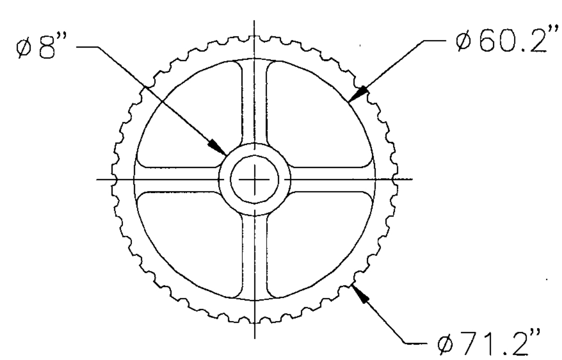



**Figure 4.11** Can Starwheel.

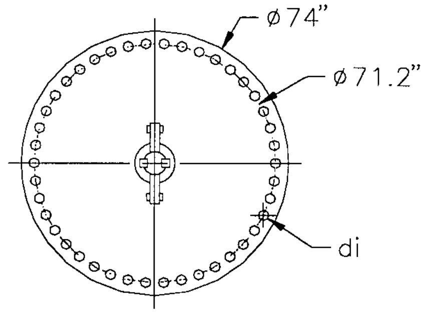



**Figure 4.12** Can Top Plate.

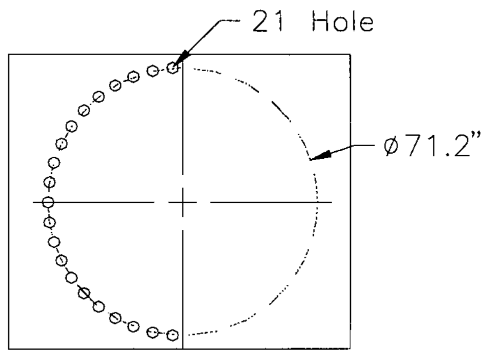



**Figure 4.13** The Divider Plate.

#### 4.2.1.2 Material Selection

Proper selection of Materials plays an important role in product design. Various design features of a machine, like strength, weight, cost, durability, and power requirements are greatly influenced by the selection of materials. This section deals with the material selection for various parts of the filling machine. The following criteria are considered for this purpose:

- High Strength,
- High Stiffness,
- Low Density,
- Impact and wear resistance,
- Chemical resistance,
- Low Water absorption,

- Possibility of Self-lubrication,
- Ease of Fabrication,
- Acceptable Formability, and,
- Low Cost.

It has been found that some plastics, e.g., PTFE (Teflon) and UHMW polyethylene, satisfy the above requirements very well. UHMW is already a well known material in the food-processing industry and is being increasingly used for making conveyor beds and chain-guides, starwheels, timing screws, tops for packing tables, transfer slide plates and formers of the form and fill packing equipment. It has properties such as high resistance to abrasion and impact, anti-stick and self-lubricating characteristics, low water absorption, and low density. These properties make it a highly sought after material for product conveying and packaging applications. It can also be punched and pressed into various shapes, sawed, machined, drilled, planed and welded for custom installations. Furthermore, UHMW is approved for direct food contact by the Food and Drug Administration (FDA). Table 4.2 lists some of the important properties of PTFE (Teflon) and UHMW polyethylene. Although stainless steel is also recommended for applications in the food industry, its high density (6 to 8 times that of UHMW) and high cost make it less desirable.

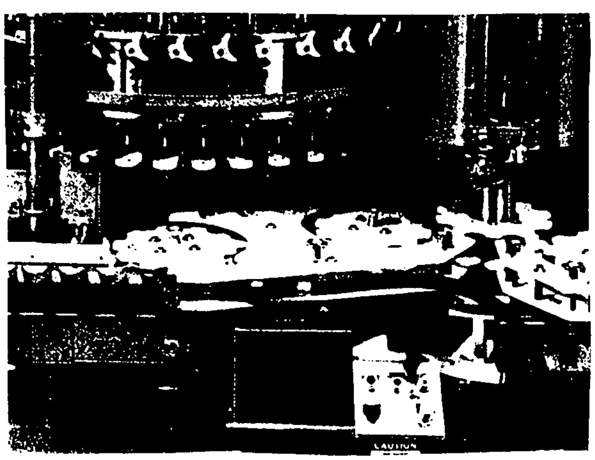


**Figure 4.14** UHMW Polyethylene Applications in the Food-Packaging Industry.

**Table 4.2** Properties of UHMW Polyethylene and PTFE (Teflon).

| Material | | UHMW Polyethylene | PTFE (Teflon) |
|---|---|---|---|
| **Property** | | | |
| Density | (lb/inch$^{3)}$ | 0.034 | 0.08 |
| Specific Gravity | Water ⇒ 1 | 0.94 | 2.1-2.3 |
| Tensile Strength | (psi) | 4000-6300 | 2000-5000 |
| Hardness | (Rockwell) | R50-64 | R10-20 |
| Impact Strength, Izod | (ftlb/in of notch) | No Break | 3.0 |
| Thermal Expansion | ($10^{-5}$ in/in °F) | 7.2 | 5.5-7.5 |
| Melt Point | (°F) | > 250 | > 600 |
| Water Absorption - 24 Hr. | (%) | < 0.01 | < 0.01 |
| Wear Factor (k) | (K X $10^{-10)}$ | 251 | - |
| Coefficient of Friction | (Dynamic) | 0.09-0.12 | 0.04-0.10 |

Based on the foregoing description, it is recommended that UHMW be chosen for constructing the rotary unit, the forming half moulds, filling plungers, can starwheel, conveyor slates (or flights), can and chain guide rails, timing screws and the table tops. Also, stainless steel chains and sprockets are recommended.

### 4.2.2 Actuation, Control and Sensing Requirements

Once the materials and physical dimensions for various component parts of the filling machine have been established, an important subsequent step in design process is to determine the drive system requirements. In the next two sections the design of the drive system, and various control and sensing requirements will be addressed.

#### 4.2.2.1 Actuation

An intermittently driven rotary table has the advantage that it requires accurate positioning only at process stations. But, the table is at disadvantage from the standpoint of inertia when compared with a chain conveyor. The chain conveyors also have the advantage of accessibility to both sides of the line for the feeding of fish portions and for adjustment and maintenance. Nevertheless, rotary tables are often a desired choice where accurate positioning is needed. It has been decided to combine these two types of components to carry out the required feeding and filling tasks. An AC electric motor is chosen for driving the rotary unit. The forming and filling operations will be accomplished using pneumatic actuators. The actuator power requirements are computed using the following procedure:

Mass of the rotor, $M_r = \frac{\rho.\pi.(D_{ro}^2 - D_{ri}^2)H_r}{4} - n.\rho.w_s.l_s.h_s + M_{sp} \cong 363$ lb (165 kg). (4.10)

where,

$\rho$ = density of the material used = .034 lb/in$^3$

$D_{ro}$ = rotary unit outer diameter = 80.2 in.

$D_{ri}$ = rotary unit inner diameter = 60.2 in.

$H_r$ = rotary unit height = 6.0 in.

$n$ = number of pockets on the rotary unit = 42.

$w_s$ = width of slot in the fixed half mould = 3 in.

$l_s$ = length of the slot in the fixed half mould = 4.5 in.

$h_s$ = height of the slot in the fixed half mould = 6.0 in.

$M_{sp}$ = mass of the spokes (4 nos.) = 0.1 $\times$ $M_r$ = 30 lb.

Note: subscripts $o$ and $i$ refer to the outside and inside diameters, respectively.

Similarly, the mass of the can starwheel can be found out by using,

$$M_{sw} = \frac{\rho.\pi.(D_{swo}^2 - D_{swi}^2)H_{sw}}{4} - \frac{n.\rho.(\pi/2)D_c^2 H_{sw}}{4} \cong 22 \text{ lb (10 kg)}. \qquad (4.11)$$

where,

$D_{swo} = 71.2$ in.

$D_{swi} = 60.2$ in.

$H_{sw} = 0.5$ in.

$D_c = 3$ in.

$n = 42.$

Now, total mass of the rotor and starwheel = 363 + 22 = 385 lb (175 kg).

Assuming that the filler is to be used for filling tall (one pound) cans, the weight of the fish in the filler = 42 lb.

Also, there will be a can lifting arrangement, filling plunger assemblies, and other associated parts, that would add to the mass of the rotary unit. Assuming that these components constitute 1/2 of the total mass of the rotary unit, we have the total mass of the rotary unit,

$M_{rtot} = 385 \times 2 = 770$ lb (350 kg).

The mass moment of inertia of the rotor can be found by using,

$$I_t \cong \frac{M_r(D_{ro}^2 - D_{ri}^2)}{8} + \frac{(M_{rtot} - M_r)(D_{swo}^2 - D_{swi}^2)}{8} = 2.04 \times 10^5 \ \text{lb}_\text{m}.\text{in}^2 \ (59.87 \ \text{Kg.m}^2). \quad (4.12)$$

Speed of the rotary unit to fill 500 cans/minute = 500/42 $\cong$ 12.0 rpm.

Since the rotary unit is indexed by 1/2 a revolution each time for filling 21 (0.5 X 42) cans, the required speed of the driving unit would be double; i.e., 24 rpm. This means that a single revolution is completed in 2.5 seconds. Assuming that the speed of the driving member is constant, the driven member should cover a distance = $\pi$ radians in 1.25 seconds. It follows that the speed of the driving member, $\omega_{driver} = 2.513$ radians/second.

The intermittent motion of the rotary unit can be achieved by choosing a suitable mechanism, like the ones shown in the figures 4.15 through 4.17. The geneva mechanism is an efficient way to accomplish this task. The four-slot geneva with two driving arms, shown in Figure 4.15, can be used to generate 180° motion and dwell periods. Table 4.3 lists some important kinematic parameters for an external geneva wheel [19, 20]. One disadvantage of the geneva mechanism is that for a particular configuration of the mechanism, the dwell and motion periods are fixed. Since it is desired that the machine be versatile, there has to be some provision for controlling the dwell-motion ratio. In order to accomplish this, an electromagnetic clutch-brake system can be added to the system. The mechanism shown in Figure 4.16 uses a drive plunger and a cam plate to generate the required intermittent motion. When the drive plunger rides the cam plate, a wedge mounted on it is forced inward into the toothed drive shaft for transmission of power to the driven shaft. The drive plunger (hence wedge) being spring loaded, disengages the drive shaft when the drive plunger disembarks the cam plate. One disadvantage of this arrangement is that the transition between the dwell and motion periods is not smooth. Figure 4.17 shows an electronic clutch brake system for generating the required intermittent motion. During actual operation, the drive shaft is kept continuously running and a clutch is used to engage or disengage the driven shaft to it. When the clutch is disengaged, the brakes are applied to the driven unit to obtain accurate indexing of driven unit.

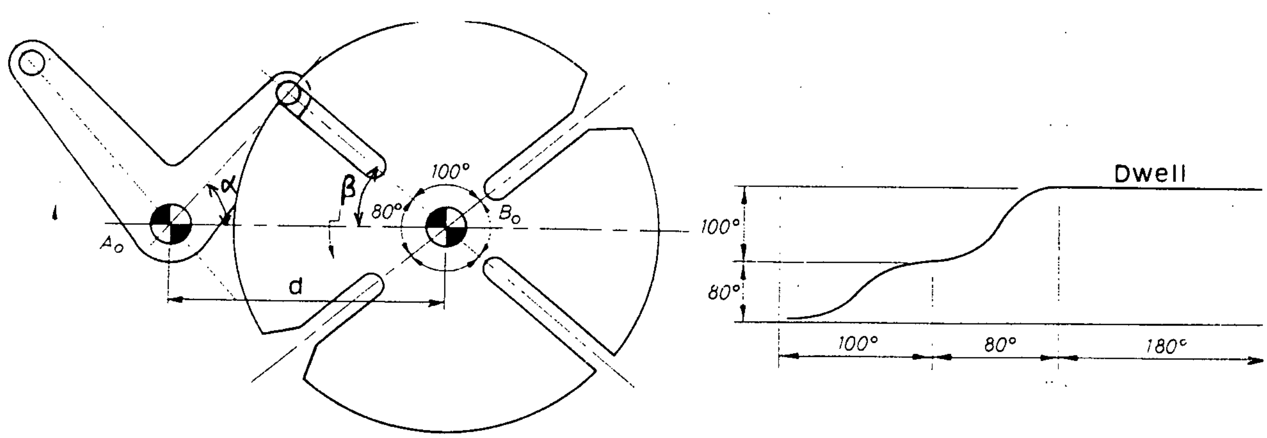



**Figure 4.15** A Two-armed Geneva Mechanism.

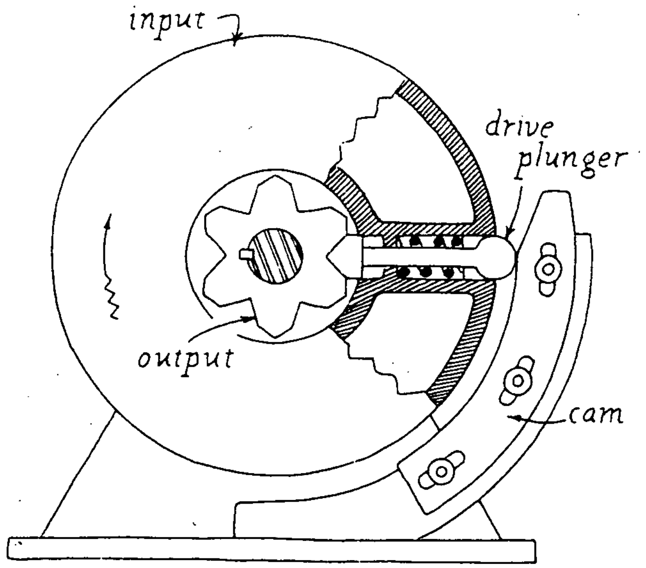



**Figure 4.16** An Intermittent Motion Mechanism.

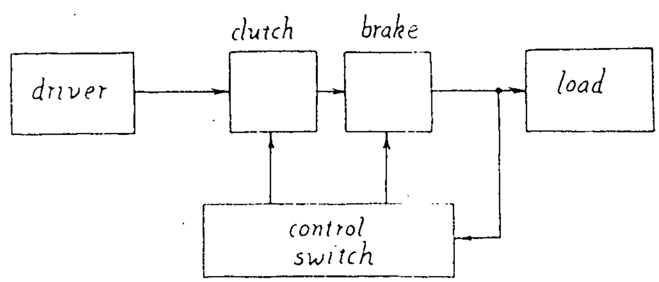



**Figure 4.17** Schematic Diagram of an Electronic Clutch-Brake System.

From the table 4.3, we have the maximum angular acceleration of driven member,

$$\alpha_{max} = 5.314 \times \omega_{driver}^2 \text{ rad/s}^2 = 33.566 \text{ rad/s}^2. \qquad (4.13)$$

**Table 4.3** Principal Kinematic Data for the External Geneva Wheel

| No. of Slots | 360°/n | Dwell period | Motion period | m and center-distance for α = 1 | Maximum angular velocity of driven member, radians per sec. equals ω multiplied by values tabulated. Crank at 0° position | Angular acceleration of driven member when roller enters slot, radians² per sec², equals ω² multiplied by values tabulated. | | | Maximum angular Acceleration of driven member, radians² per sec², equals ω² multiplied by values tabulated | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | α | β | Multiplier | α | β | Multiplier |
| 3 | 120° | 300° | 60° | 1.155 | 6.458 | 30° | 60° | 1.729 | 4° | 27° 58′ | 29.10 |
| 4 | 90° | 270° | 90° | 1.414 | 2.407 | 45° | 45° | 1.000 | 11° 28′ | 25° 11′ | 5.314 |
| 5 | 72° | 252° | 108° | 1.701 | 1.425 | 54° | 36° | 0.727 | 17° 31′ | 21° 53′ | 2.310 |
| 6 | 60° | 240° | 120° | 2.000 | 1.000 | 60° | 30° | 0.577 | 22° 55′ | 19° 51′ | 1.349 |

Therefore, maximum torque required to drive the rotor is given by

$$\tau = I_t.\alpha_{max} = (2.04 \times 10^5) \times 33.566 \text{ lb}_m.\text{in}^2/\text{s}^2 \text{ (2.00 kNm)} \qquad (4.14)$$

An AC electric motor with 1200 rpm (with a suitable gear ratio) will be used to drive the rotary unit. The gear-ratio ,

$$GR = \frac{\text{Motor Speed}}{\text{Speed of driving member}} = 1200/24 = 50. \qquad (4.15)$$

Accordingly, the motor must provide a torque of,

$$\tau_{max} = \tau / GR \cong 1.37 \times 10^5 \text{ lb}_m.\text{in}^2/\text{s}^2 \text{ (40.19 Nm)}. \qquad (4.16)$$

In one second, during which the motor shaft turns 20 revolutions, the work capacity equal to:

Work = $20 \times 2\pi \times (1.37 \times 10^5)$ $\text{lb}_m.\text{in}^2/\text{s}^3$ (5.05 kJ). (4.17)

The required horsepower = 5.05 hp × 1.34 hp/kW = 6.76 hp. (4.18)

Assuming a mechanical efficiency of $\eta_{mech}$ = 87% (85% - 90%, typical), we have

Required hp = 6.76/0.87 = 7.77 hp. (4.19)

Similarly various dimensions of the geneva can be determined by the procedure given below.

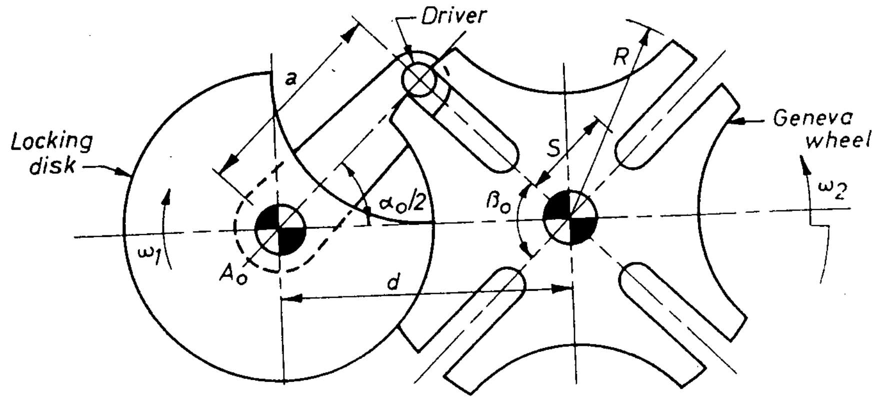



**Figure 4.18** Various Dimensions for Geneva Mechanism.

From the Figure 4.18, we have:

$\beta_0 = 90^\circ$,

$R = d.Cos(\beta_0/2)$, (4.20)

$a = d.Sin(\beta_0/2)$, (4.21)

$\alpha = 169.4^\circ$,

$\alpha_1 = 0$ ,

$\beta = Sin^{-1}\left[\frac{a}{r}Sin(\alpha)\right]$, (4.22)

$$r = \sqrt{a^2 + d^2 - 2.a.d.COS(180 - \alpha)} \tag{4.23}$$

$$\alpha_2 = \frac{a\omega_1^{\ 2}.Sin(\beta - \alpha) - a\alpha_1.Cos(\beta - \alpha)}{r} + \frac{a^2\omega_1^{\ 2}.Sin(2\beta - 2\alpha)}{r^2}. \tag{4.24}$$

Also, force $F_{12} = \dfrac{(I_G + I_t)\alpha_2}{r}$ (4.25)

where,

$I_G = \dfrac{1}{2}\rho\pi R^4 t$ is the mass moment of inertia of the geneva wheel. (4.26)

$t$ = thickness of geneva = 0.5 inch.

By varying the size of the geneva wheel, it is possible to find a value of $R$ so that $(F_{12})_{max}$ is a minimum. The computer generated solution is presented in Table 4.4.

Compressive stresses induced by force $F_{12}$ are within reasonable limits for the material UHMW polyethylene. The important dimensions of the geneva wheel are as follows:

$d$ = 34.0 in.

$R$ = 24.0 in.

$a$ = 24.0 in.

$$S = \frac{R}{Cos(\beta_0/2)} - R.Tan(\beta_0/2) = 9.94 \text{ in.} \tag{4.27}$$

$t$ = 0.5 in.

$r_f$ = 0.5 in.

The mass moment of inertia of the geneva wheel, $I_G$ = 8917.32 $lb_m.in^2$ (2.615 $Kg.m^2$)

(4.28)

Hence the modified horse power requirement can be determined as follows:

HP required to index the rotary unit = $\dfrac{(I_t + I_G).\alpha_{max}.2.\pi.N_{motor}}{1000.GR.\eta_{mech}}$ (kW) X 1.34 (hp / kW) = 8.19 hp

(4.29)

where, motor rpm , $N_{motor}$ = 20 rev/s.

**Table 4.4** Computer-generated Solution for the Optimal Design of a Geneva Wheel.

| ***d*** (inch) | ***R*** (inch) | ***r*** (inch) | $F_{12}$ (N) |
|---|---|---|---|
| 10.000000 | 7.070348 | 3.314906 | 1506.548286 |
| 11.000000 | 7.777382 | 3.646397 | 1371.143167 |
| 12.000000 | 8.484417 | 3.977887 | 1258.751804 |
| 13.000000 | 9.191452 | 4.309378 | 1164.141518 |
| 14.000000 | 9.898487 | 4.640868 | 1083.580997 |
| 15.000000 | 10.605522 | 4.972359 | 1014.339837 |
| 16.000000 | 11.312556 | 5.303850 | 954.375758 |
| 17.000000 | 12.019591 | 5.635340 | 902.132218 |
| 18.000000 | 12.726626 | 5.966831 | 856.403482 |
| 19.000000 | 13.433661 | 6.298322 | 816.242307 |
| 20.000000 | 14.140695 | 6.629812 | 780.895318 |
| 21.000000 | 14.847730 | 6.961303 | 749.756847 |
| 22.000000 | 15.554765 | 7.292793 | 722.335367 |
| 23.000000 | 16.261800 | 7.624284 | 698.228678 |
| 24.000000 | 16.968834 | 7.955775 | 677.105292 |
| 25.000000 | 17.675869 | 8.287265 | 658.690299 |
| 26.000000 | 18.382904 | 8.618756 | 642.754480 |
| 27.000000 | 19.089939 | 8.950246 | 629.105849 |
| 28.000000 | 19.796974 | 9.281737 | 617.583003 |
| 29.000000 | 20.504008 | 9.613228 | 608.049848 |
| 30.000000 | 21.211043 | 9.944718 | 600.391384 |
| 31.000000 | 21.918078 | 10.276209 | 594.510300 |
| 32.000000 | 22.625113 | 10.607699 | 590.324211 |
| 33.000000 | 23.332147 | 10.939190 | 587.763398 |
| 34.000000 | 24.039182 | 11.270681 | 586.768941 |
| 35.000000 | 24.746217 | 11.602171 | 587.291182 |
| 36.000000 | 25.453252 | 11.933662 | 589.288433 |
| 37.000000 | 26.160286 | 12.265152 | 592.725904 |
| 38.000000 | 26.867321 | 12.596643 | 597.574792 |
| 39.000000 | 27.574356 | 12.928134 | 603.811515 |
| 40.000000 | 28.281391 | 13.259624 | 611.417058 |

Similarly, the power requirements for the conveyor can be determined as follows. In view of the light loading involved, a one-inch pitch conveyor series is selected. The selection is modified to standard pitch precision roller chain (#80) in view of the required support by rollers. (Roller-chain drives are well known for their applications in the packaging industry and can easily handle rotational speeds upto 10,000 rpm.)

Chain weight = 1.73 lb/ft.
Since one cycle of the machine would fill 21 cans, there will be an equal number of feeding stations @ 6.0 inch pitch on one side of the conveyor. It follows that the distance $C$ between the two sprockets has to be greater than $21 \times 6 = 126$ in or 10.5 ft.

The slates will be made of UHMW polyethylene. The weight of the attachments (slates) per foot of the conveyor is calculated as follows:

Weight of one slate, $W_{sl} = \rho . l_{sl} w_{sl} h_{sl} = 0.2975$ lb. (4.30)

where,
$\rho$ = density of UHMW polyethylene = 0.034 lb/in$^3$.
$l_{sl}$ = slate length = 7.0 in.
$w_{sl}$ = slate thickness = 0.25 in.
$h_{sl}$ = slate height = 5.0 in.

Weight of the slates per foot of conveyor length = $\dfrac{n_{sl} . W_{sl}}{p}$ X 12 = 1.19 lb/ft, (4.31)

where,
$n_{sl}$ = number of slates per filling station = 2.
$p$ = pitch of the conveyor = 6.0 in.

It follows that the weight /ft of conveyor length, $W_c = 1.73 + 1.19 = 2.92$ lb. (4.32)

Maximum conveyed weight per foot of the conveyor, $W_m = \dfrac{w_{can}}{p}$ X 12 lb/ft. = 2 lb/ft. (4.33)

Conveyor speed, $S = \dfrac{2 \text{ X } 500 \text{ X } 6}{12} = 500$ ft/minute $\approx 3$ m/sec. (4.34)

Since this is a class 2[1] conveyor application [17], the conveyor pull can be determined using the formula,

---

[1] Chain $\rightarrow$ rolling, material $\rightarrow$ sliding

$$P_m = C.\left(2.f_1.W_c + f_2.W_m + \frac{f_2.BD.h^2}{100}\right) \cong 34.4 \text{ lb}, \tag{4.35}$$

where

$C$ = center distance between two sprockets = 25.0 ft.

$f1$ = coefficient of rolling friction, for #80 chain = 0.10 to 0.14 = 0.12 (say).

$f2$ = coefficient of friction for fish sliding on smooth surface ≅ 0.15.

$BD$ = material bulk density = 62.5 lb/ft$^3$ for salmon.

$h$ = height/width of material rubbing against conveyor walls ≅ 2 in.

The chain pull is within the range of the working loads for #80 precision roller chain.

Assuming 87% mechanical drive efficiency, the horse power required is computed as,

$$\text{HP} = \frac{1.15\ S.P_m}{33000} = 0.6 \text{ hp}. \tag{4.36}$$

The total horse power required to run the rotary unit = 8.19 + 0.6 = 8.79 hp. (4.37)

Hence a 10 hp, 1200 rpm motor with 50:1 gear ratio is chosen for the job. For greater positioning accuracy, the use of an electronic clutch and brake system is recommended.

The various other dimensions for the conveying system are as follows:

Pitch circle diameter of the sprocket, $D_{psp}$ = 40.107 in.

Total number of teeth on each sprocket, $N_t$ = 252 @ 1.0 inch pitch.

Length of the chain = $N_t$ + 2 X $C$ = 252 + 2 × 25 × 12 = 852 in. = 71 ft. (4.38)

The driven sprocket is made adjustable so as to compensate for chain sag and associated catenary tension.

The electro-pneumatic actuators are chosen for carrying out the forming and filling operations. Some of the advantages of using pneumatic actuators for reciprocating motion are:

- Actuating fluid cost is very small if air is used, whereas fire-resistant hydraulic fluid is more costly.
- It does not constitute a fire hazard.
- The fluid is very light in weight (therefore, low weight to power ratio).
- Fluid exhausts to the atmosphere, and hence return lines form the actuator are not required.
- Fluid leaks are not important as the fluid is not harmful to the surrounding products, equipment, and environment. This feature is especially important in food processing industry.
- Most pneumatic actuators are relatively inexpensive and require little maintenance.
- Compressed air can actuate devices faster than a hydraulic fluid can.

One of the obvious disadvantages of using compressed air in actuators is its compressibility. But through the use of electronic control this problem has been overcome, and repeatable accuracy to about 0.0004 in. is achievable for velocities up to 11.5 ft/s and payloads up to 45 lb.

The air requirements for driving the forming plunger are determined as follows:

Based on existing applications, a single acting cylinder with 2.0 in. bore is chosen for operating at 125 psi pressure. Since the forming and filling operations are to be carried out in the time frame as shown in Figure 4.19, the time chosen for a single cycle operation of forming plunger is 0.16 seconds.

For a single forming or filling plunger operation, cycle rate would be $= \frac{1}{2.5} \times 60 = 24$ cycles/min. (4.39)

Piston Stroke = 7.0 + 4.5 = 11.5 in. (4.40)

The volumetric flow rate ($V_1$) at 125 lbf/in$^2$ is given by:

$$V_1 = \frac{\text{Area X Stroke X Cycle rate}}{1728} = \frac{3.142 \text{ X } 2^2 \text{ X } 10 \text{ X } 24}{4 \text{ X } 1728} = 0.5 \text{ ft}^3\text{/min. @ 125 psi.} \quad (4.41)$$

From Boyle's law[2] for isothermal conditions, free air consumption is given by

$$V_2 = \frac{p_1 V_1}{p_2} = \frac{(125 + 14.7) \text{ X } 0.5}{14.7} = 4.75 \text{ ft}^3\text{/min. free air.} \quad (4.42)$$

### 4.2.2.2 Sensing and Control Requirements

Various features used in the proposed design; e.g., no can - no fill activation, adjustment for various can sizes (diameter, height), and target weight control call for appropriate sensors and controllers. This section briefly outlines the control and sensing requirements for these functions.

No can - no fill activation, as the name implies, makes sure that the filling takes place only if there is a can available for this purpose. Similarly, if the portions corresponding to a particular can are missing, that can should be immediately removed from the main line and the forming and filling plungers need not be fired for that particular can. This can be achieved by using either load cells or proximity sensors on each can lifting assembly. The use of load cells would serve several purposes, as the information from the load cells (after the filling has been carried out) can be sent as an input to the post-filling inspection set-up for weight compensation. The output from the load cells also helps in the stroke adjustment of spring loaded can lifters. The main purpose of the can lifters is to make sure that cans are in contact with the bottom plate of the rotary unit without any excessive pressure exerted on them. When one or more cans from a line are missing, the load cell would give no (zero) reading, and this information can be used to stop the activation of forming and filling plungers for those particular positions. The missed fish portions would travel along with the conveyor and then recirculated. The information

[2] If temperature correction is desirable, for instance, if air at the work station is delivered at $T_1$ °F and correction to $T_2$ °F is necessary, the general gas law can be used.

about those particular pocket locations would be sent to the feeding station (where the new portions are fed) to avoid any double feeding. Simple optical sensors can also be used to detect the presence and absence of an object, but they may not be very reliable in humid conditions and in the presence of food particles. The control can be easily accomplished using simple boolean logic. The truth table for the circuit is shown in Table 4.5.

**Table 4.5.** Truth Table for No can - No Fill Activation Logic

| **INPUT** | | **OUTPUT** | | |
|---|---|---|---|---|
| $C_{in}$ | $P_{in}$ | $P_{form}$ | $P_{fill}$ | $P_{sep}$ |
| F | F | F | F | F |
| F | T | F | F | F |
| T | F | F | F | T |
| T | T | T | T | F |

Here,

$C_{in}$ = boolean variable to indicate the presence of a can.

$P_{in}$ = boolean variable to indicate the presence of fish portions.

$P_{form}$ = forming plunger actuation on/off = $C_{in}$ .AND.$P_{in}$.

$P_{fill}$ = filling plunger actuation on/off = $C_{in}$ .AND.$P_{in}$.

$P_{sep}$ = air-nozzle on/off for ejecting an empty can = $C_{in}$.AND.$\overline{P_{in}}$ .

For weight compensation of underfilled cans, the information from the load cells located on each can lifter assembly is sent to the post-filling inspection setup. This information is used for fine compensation of the underweight cans. This arrangement is described in detail in Section 4.3. The particular design also calls for stroke adjustment of the forming and filling plungers in order to accommodate cans of different sizes. These are one time adjustments, done only when changing over to a different can size/shape. This can be accomplished by using a limit switch, and then adjusting the position of the limit-switch to get the desired stroke length. However, a more efficient way of doing this is to use either magnetic or electronic sensors mounted on the cylinder itself to detect the piston position. In any event, the piston signal obtained by any of these methods may be used to open or close a valve so as to slow down or stop the piston at any desired point. For more sophisticated control, a pneumatic feedback servo could be used.

### 4.3 Post-Filling Stage

As described in Chapter 3, the purpose of the post-filling operations is to check the quality of the end product for any deviations from what is desired, and if need be, rectify those defects. The deviation can be in the form of underweight, overweight, or poorly filled cans; specifically, cans with cross-packs, skin and bones hanging on the flange, and improper head space. Post-filling operations are addressed next.

#### 4.3.1 Some Recommendations

The defects in a filled can may be classified into two categories - visual (or qualitative) and quantitative. The qualitative defects can be detected using machine vision. The problem of insufficient head-space can be checked by using height sensors. These defective cans are then segregated onto an auxiliary line, where they are repaired in a visual defect repair station before being returned to the main line. A pneumatic blower (jet) can be used to transfer the cans between the main and the auxiliary (repair) lines. The visually satisfactory cans are then inspected for possible underweights. On-line weighing is used for this purpose. Any underweight cans are passed onto an auxiliary line, where they are repaired at the weight compensation unit before being returned to the main line.

The compensation amount fish meat can be added in a secondary filling arrangement. The final amount, which would be in the form of a fine paste (slurry), may be injected using a fine nozzle. The filling amount can also be controlled by adjusting the stroke of the plunger. The above arrangement could be implemented in the filling stage as well. One way to accomplish this would be to keep track of each portion group of fish, and then add the compensation amount just before carrying out the actual filling operation. This can be achieved by embedding the injecting nozzle within the filling plunger.

Stroke of the piston, $x = \dfrac{W_{comp}}{\rho . A_t}$ in. (4.43)

where,

$W_{comp}$ = compensation weight to be added

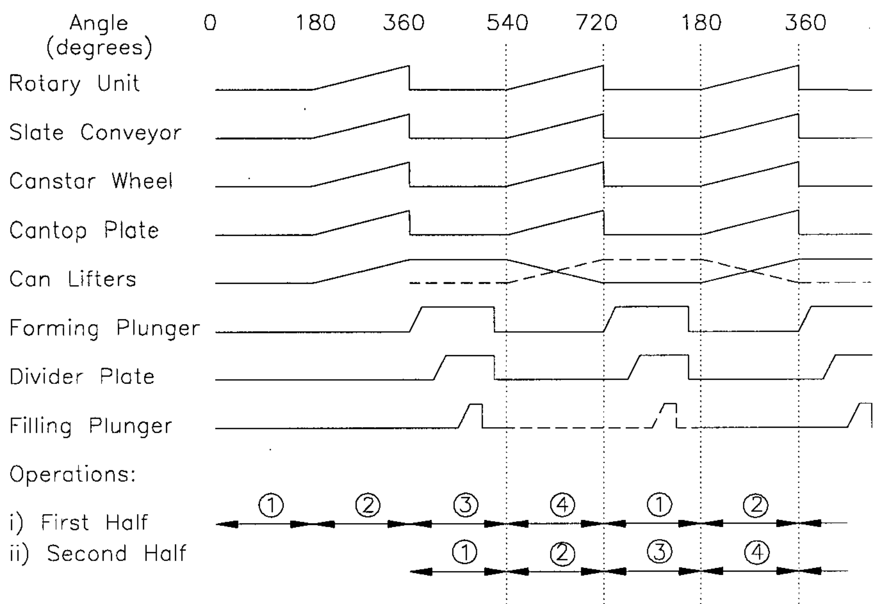
$\rho$ = density of slurry

$A_t$ = inside cross-section area of the tube.

Once the required stroke of compensation is determined, the piston is displaced by that amount at the appropriate time, using the weight-compensation controller.

### 4.4 Description of Filling Operation

Figure 4.19 shows the sequence of various operations involved in the filling process. The pre-weighed portions (portion groups) of fish are fed into the compartments of the slate conveyor at feed stations numbered 1, 2, 3, ...... etc. Then, the rotary unit is indexed through 180° by a two-arm geneva mechanism located underneath the rotary unit. The sprocket that is mounted on the rotary unit drives the slate conveyor such that the portions are positioned in front of the respective filling chambers marked A, B, C, ...... etc (Figure 4.20). At the same time, the cans are fed into the rotary unit by means of a synchronizing screw. As the unit indexes, these cans are lifted by can-lifters that are located underneath the cans. The lift assemblies are actuated individually. Load cells mounted on these lift assemblies make sure that the cans are in optimal contact (without excessive pressure) with the top plate. During the dwell period, the forming plungers transport the fish portions into respective moulds and the portions are formed into the desired can shape. The divider plate located underneath the table on which the fish portions rest, is then indexed to expose the portions to the cans located below. Next, the filling plungers are actuated to fill the portions into the respective cans. Before the rotary unit indexes by another 180°, the divider plate will index back to its original unexposed position. As the unit indexes, the can lifter assemblies will retract back to their low positions. The filled cans are then sent to the workcell post-filling inspection and repair. The whole process is repeated to accomplish the filling task in a continuous manner.




Glossary

| | |
|---|---|
| ① | Fish portions in |
| ② | Empty cans in |
| ③ | Forming / Filling Operation |
| ④ | Filled cans out |

**Figure 4.19** Activity Cycle of a Filling Operation.

## 4.5 Design Features of the Filling Machine

Listed below are some important design features of the proposed filling machine and associated advantages.

- The new machine is capable of filling up to 500 cans per minute, which is twice what is possible with the existing equipment. This speed can be further doubled (i.e., 1000 cans per minute) by making the machine double acting as shown in the Figure 4.20.
- Since weight-based filling is used in the present design, initially, all the cans are filled slightly below the target weight. The compensation amount of fish meat is added either before the actual filling operation, or during the post-filling operations. This arrangement will result in better weight control, and hence improved filling accuracy and yield.

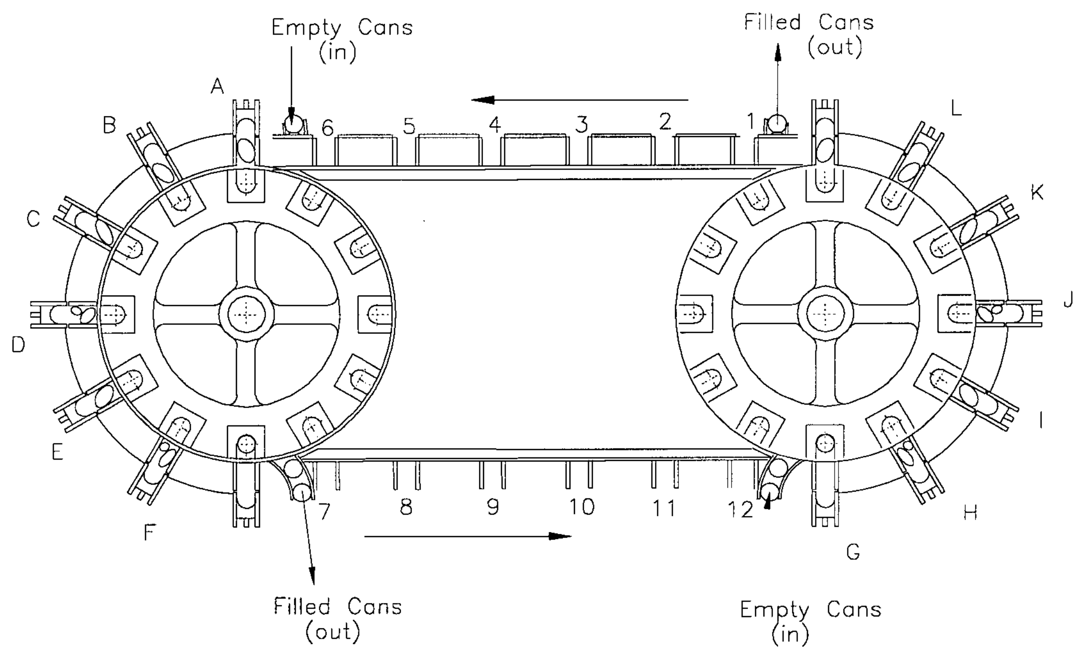



**Figure 4.20** A Double-acting Rotary Filler with Slate Conveyor.

- Since a weight-based approach is used, the portions are not subjected to excessive forces and deformations as in the case of existing machinery. As a result, the new machine would result in a higher quality product with improved presentation and minimal wastage.
- The modular design makes the new machine versatile (flexible), as a variety of can shapes and sizes can be accommodated by changing a few components. The proposed design can accommodate can diameters upto $3\frac{7}{16}$ in. and can heights in the range 1.0″ to 4.5″. The

changeover would be possible in less than an hour by an experienced operator. Also, the weight-based filling approach makes the machine suitable for handling a variety of other products like, other species of fish, vegetables, and other meat products. The machine would be able to handle both cannery dressed and skinless-boneless salmon.

- In the proposed design care has been taken to incorporate useful reliability and safety features. (e.g; No can - no fill activation feature). Also, the modular nature of the design makes it easily accessible for fast repair and maintenance. Furthermore, it is suggested that water spraying nozzles be placed on the rotary unit periphery opposite to the forming plungers. In this manner, provision is made for a cleaning cycle, just before starting or just after stopping the machine. In case of accidental jamming of the machine, the electromagnetic clutch brake system can be triggered immediately to prevent damage to the machinery and its operator.
- Gentle handling of cans is a feature of the proposed design and is related to safety of the machine. In the proposed design, most of the filling components, and conveyor parts are made of UHMW polyethylene. This will make sure that the cans are not subjected to excessive forces or scratching. This is important, as the scratches on a can surface will wipe off the protective coating thereby making it susceptible to corrosion.

### 4.6 Design Limitations

The proposed design has some limitations as well, as listed below.

- There is a limit on the size (cross-section) of the fish that can be fed into the filler. For this reason, the fish have to be sorted into different categories, as suitable for filling cans of different sizes.
- The speed of operation of the proposed filling machine would be limited by the speed at which the portion sorting and grouping operations are carried out. Multiple lines may be required for high speed operation.

- Size of the proposed machine is another limiting factor. Although there are filling machines which occupy more than $6m^2$ of floor area, large space requirements might be a hindrance to its use at some plants.
- Although an attempt has been made in the design to keep the inertia of the moving parts to reasonably low values, because of the intermittent motion involved, it may pose problems, like wear and tear of the moving parts and noise.

# Chapter 5

## Cost Benefit Evaluation

Automation of can-filling operations has significant economic advantages. The present chapter provides a cost-benefit analysis of the proposed design, leading to an economic justification [26]. Despite the lack of sufficient information, as much of the data on the existing machines is proprietary, by making some valid assumptions it can be shown that the new machine should be able to provide a rate of return that is at least twice that of the existing machine. According to a rough estimate, by cutting down on wastage and labor requirements alone the new machine would save at least 1.5 million dollars for every one million 48 lb cases of salmon processed.

### 5.1 Benefits of using the New Machine

Some of the obvious benefits of using the new machine would be higher filling speed, reduced wastage, and reduced labor requirement. By assigning some reasonable figures to these parameters, it can be shown that a new machine would be able to completely pay for itself in two years.

In a typical year, British Columbia packs about one million 48 lb cases of salmon. Assuming equal production (by amount) of both 1/4 lb and 1/2 lb cans, 144 million cans are filled annuallly, i.e., 48 million 1/2 lb cans, and 96 million 1/4 lb cans. It has been observed that a single machine running at 200 cans per minute, in two shifts (ten hours each) a day in a two-month season fills about 10 million cans (assuming 70% utilization). Now, in order to fill 144 million cans annually, 15 filling machines are required, such that

Number of 1/2 lb machines = 5

Number of 1/4 lb machines = 10

The use of new machine would result in many benefits, as outlined below:

### I. Reduced Wastage

The existing machinery in the salmon can-filling plants results in excessive wastage of fish meat in the form of slurry. The wastage is even more pronounced in the processing of skinless and boneless salmon. Since the canning season is very short, the processing companies usually do not pay much attention investigating the wastage of salmon during the process of canning. However, according to rough estimates, this wastage is 2 to 3 gm per filled can. The proposed weight-based approach to the filling operation would ensure that the fish portions are not subjected to excessive stresses and strains during the feeding and forming operations, and hence would lead to reduced wastage. Suppose that when a proposed machine is employed, we are able to save one gm of meat per filled can. This would result in annual savings of 144 tonnes of salmon.

Sockeye and pink are the most widely canned species of salmon. According to the available figures, fish-processors pay \$1.50 to \$2.50 per lb for the raw sockeye and \$0.37 to \$0.50 per lb for the pink. It can be seen from Figure 5.1 that these two species contribute equally to the canned salmon pack. Consequently, average price paid by the processors per kg of salmon is \$2.64. Hence, as a result of the extra 144 tons of salmon meat that is saved, there is an additional revenue of \$380,000 from raw material.

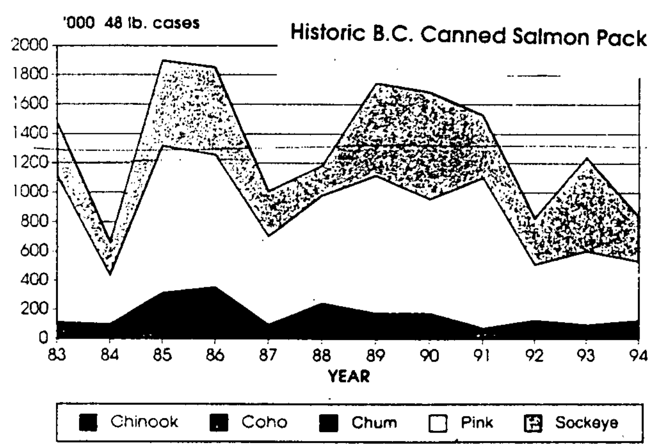



**Figure 5.1** Canned Salmon Pack for the Year 1994.

**II. Reduced Labor Requirement**

Existing machinery in the can-filling plants employs 10 to 11 workers on the 1/4 lb and 7 to 8 workers on the 1/2 lb machines. Each new machine would replace at least 5 workers. According to the available data, the starting wage of a fish worker is $13.00 per hour. After 400 hours of employment, the hourly wage would be raised to $14.90. Assuming the minimum wage of $13.00 per hour, and 240 hours of work per month per each worker, the monthly earnings is $3,120. It follows that the wages saved per worker by a machine operating two shifts a day, in a two month season is $12,480. Hence, wages saved through 15 machines is $936,000.

**III. Increased Filling Speed**

Since the filling speed of the proposed machine is twice that of the machinery in use, it would be possible to complete the entire canning operation in a month. This would result in further savings of $468,000 in wages. Accordingly, the total savings in wages would be $936,000 + $468,000 or $1,404,000. Now, by combining all these savings, we have

Savings through raw material recovery = $ 380,000

Saving through labor reduction = $1,404,000

Total savings = $1,784,000

Which is approximately 0.5% of the total annual sales recorded by a major fish processing company processing salmon and herring roe.

It follows that the total savings per machine is approximately $110,000. The replacement cost of the existing can-filling machinery is known to be in the range $150,000 to $200,000. It is estimated that the cost of the proposed machinery also would lie within this range. Hence, based on the estimates that are considered reliable, the new machine would be able to completely pay for itself in two canning seasons.

## 5.2 Rate of Return

A procedure for determining the rate of return for the new machine is given in this section. The following nomenclature is used :

$C_i$ = Cost of capital ( Equipment cost, installation cost, etc.) for a machine,

$M_i$ = Maintenance cost / year for a machine,

$L_i$ = Annual labor cost,

$D_i$ = Annual administrative expenses,

$E_i$ = Power cost / year,

$R_i$ = Raw material cost / year,

$O_i$ = Other miscellaneous expenses,

$I_i$ = Annual sales figures, and,

$B_i$ = Net annual benefits.

where, subscript $i = 1$ denotes an existing machine, and $i = 2$ denotes the proposed; flexible machine. Assuming a useful life-span of 10 years for both machines, and MARR (Minimum attractive rate of return) before taxes = 25% on the investment, we have

$$B_i = I_i - ( R_i + L_i + D_i + M_i + E_i + O_i ), \qquad (5.1)$$

with $i = 1, 2$ for the existing and proposed machines, respectively. Now, the actual rate of return can be determined by using :

$$C_i = B_i (P_i / A_i , r, N) \qquad (5.2)$$

where,

$A_i$ = End of period cash flows (benefits) for the $i$th machine,

$P_i$ = Initial investment for the $i$th machine,

$r$ = Rate of return, and,

$N$ = Useful life-span of the machine.

$A_i/P_i$ denotes the capital recovery factor for the $i$th machine. But $C_i$ and $B_i$ are known. Hence, the rate of return can be determined from compound interest computation.

According to our design requirements, the operating speed of the new machine is twice that of the existing machine. Also, assuming that all other costs, i.e; total sales, raw material, labor, administrative, maintenance, power, and other expenses are modified by factors of $K_I$, $K_R$, $K_L$, $K_D$, $K_M$, $K_P$ *and* $K_O$ respectively, we have

$$B_2 = (1+K_I)I_1 - (K_R R_1 + K_L L_1 + K_D D_1 + K_M M_1 + K_P P_1 + K_O O_1) + Z. \qquad (5.3)$$

Where $Z$ denotes other (intangible) benefits gained by using the new machine, such as higher product quality, and reduced need for training and hiring of new workers. Also, it should be noted that the $K_i$ values are all less than unity. Because of the dwindling stocks of salmon, despite the filling speed of the proposed machine being twice that of the existing machinery, the number of cans filled would be about the same. The labor costs would be cut to almost one-quarter. It is clear from the above expression that $B_2 > B_1$. By using a maximum limit of $200,000 on the cost of the proposed machine and minimum savings of $110,000 as estimated in the previous section, the minimum rate of return ($r_m$) can be calculated as follows:

$$C_i = B_{i1}(1+r)^{-1} + B_{i2}(1+r)^{-2} + \ldots\ldots\ldots\ldots + B_{iN}(1+r)^{-N}. \qquad (5.4)$$

where $B_{ik}$ denotes the benefits at the end of $k$th period for the $i$th machine. Assuming equal benefits, we have

$$B_{i1} = B_{i2} = \ldots\ldots\ldots = B_{ik} = B_i \text{ (say)}. \qquad (5.5)$$

Therefore equation 5.2 can be rewritten as follows:

$$C_i = B_i.\sum_{j=1}^{j=N}(1+r)^{-j} = B_i.\frac{(1+r)^N - 1}{r(i+r)^N} = B_i.(P_i / A_i, r, N). \qquad (5.6)$$

Figure 5.2 shows total benefits vs rate of return plot for a filling machine costing $200, 000. So, if the total benefits are known, the rate of return can be easily found out from the plot.

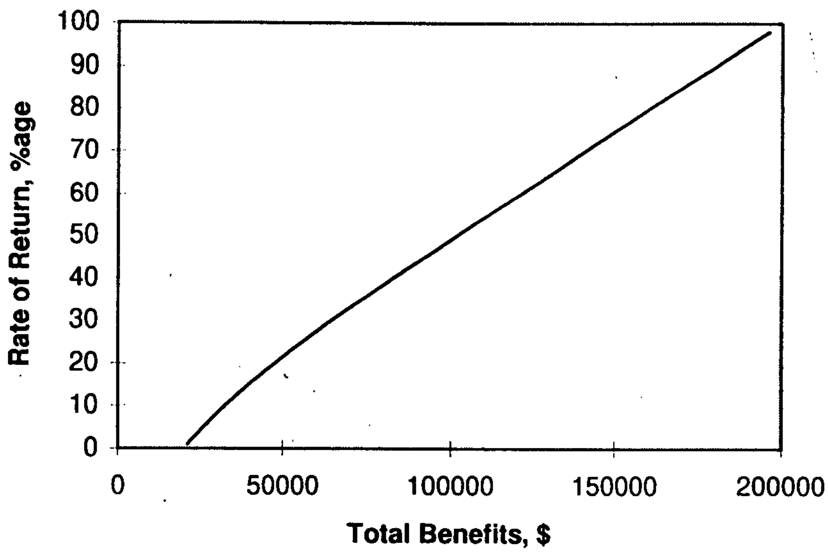



**Figure 5.2** Total Benefits Vs Rate of Return Plot for a Filling Machine Costing $200,000.

Substituting the values, we have

$$\frac{2\times 10^5}{1.1\times 10^5}=\frac{(1+r_m)^{10}-1}{r_m(1+r_m)^{10}} \tag{5.7}$$

$r_m \cong 54\%$

Hence we may conclude that even if the new machine costs the same as the existing machine, the rate of return would be at least twice as much as that of purchasing one of the existing machines.

# Chapter 6

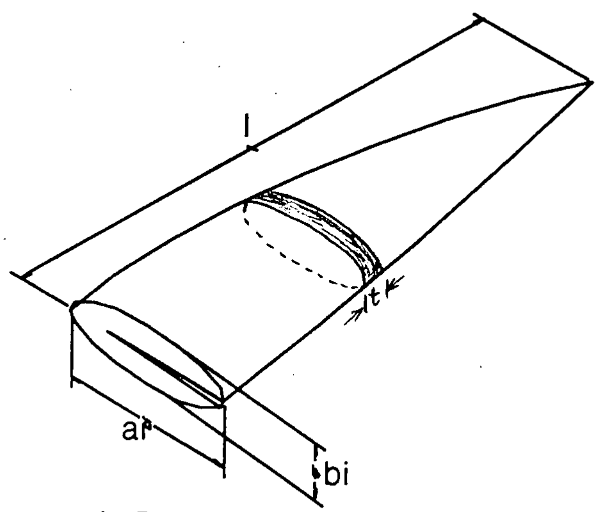
## Experimental Development and Evaluation

Experimentation forms an important part in the process of design development of machinery. In the previous chapters, we have developed an appropriate design for an automated can filling system, and then transformed these concepts into component designs that could be evaluated. The evaluation can be either analytical or experimental, or a combination of the two. Some analysis of the design, including an economic analysis has been presented in the foregoing presentation. Apart from this, a number of experiments have been conducted, to find out mechanical properties of fish. Also, a laboratory prototype has been built to test the performance of forming and filling operations in the proposed can filling system. The present chapter will describe these experimental developments and testing.

### 6.1 An Innovative Approach to Portioning of fish

Experiments have been conducted to test the cutting approach outlined in Chapter 4. As indicated in Figure 6.1, the cross-sectional profiles of the fish are captured successively along its length using line-scan cameras. Since the cross-section of fish along its length is somewhat elliptical, its weight can be estimated by using the formulae presented in Table 6.1. Although the proposed arrangement uses physical measurements to capture the cross-sectional profiles of a fish, the same will be accomplished using line-scan cameras or optical fibers in the actual setup. For our testing purposes, however, the fish profiles were manually transferred onto a piece of paper by physical measurements. These profiles were divided into 0.5 cm wide sections along the length of the fish. The density of the fish was determined by using the Archimedes' principle. Then, the weight of the fish was determined by using the equations presented in Chapter 4. The results of the experiments are presented in Table 6.1.

As can be seen from the results, the maximum error has occurred in the case of frozen fish. The length of the fish used for the above experiments averaged about 42 cm (i.e., 84 scans of 0.5 cm. spacing). In ¼ lb filling arrangement, the length of an individual portion of fish is set within from 0.8 to 1.0 in. Consequently, there will be a maximum of 16 cut portions per fish. Dividing the maximum error of 29.65 gm (See Table 6.1) equally among the 16 portions, we have, the average error per portion = 1.9 gm. However, in practice, the frozen fish is thawed before sending to the cutting machine. Note that, the maximum average error per portion for the thawed fish = 7.9/16 = 0.5 grams, from the results in Table 6.1. This is quite impressive, particularly in view of the fact that the experiments were performed at low resolution.




Determination of Individual Portion Lengths

**Figure 6.1** Use of the Cross-sectional Profile to Determine the Weight of a Fish.

This same information can be utilized to cut the fish into portions of equal weight. After the cross-sectional profiles of a fish have been captured, the fish may be overlapped with an appropriate lag so as to ensure uniform distribution of weight along the length of the overlapped chain of fish. The principle behind this procedure has been presented in Chapter 4.

**Table 6.1** Estimation of Weight of a Salmon from its Cross-sectional Profile.

| Fish # | $W_1$ (gm) | $h$ (cm) | ρ (gm/cm³) | $\Sigma a_i b_i$[1] (cm²) | $t$ (cm) | $W_2$ (gm) | $k = W_1/W_2$ | $W_c$ (gm) | Error (gm) | %age Error |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1300.9 | 2.0 | 1.03 | 3463.23 | 0.5 | 1360.0 | 0.9565 | 1308.8 | 7.9 | 0.61 |
| 2 | 1208.2 | 1.9 | 1.00 | 3192.61 | 0.5 | 1253.7 | 0.9637 | 1206.5 | 1.7 | 0.14 |
| 3 (Frozen) | 1900.4 | 3.0 | 0.99 | 5091.42 | 0.5 | 1999.4 | 0.9505 | 1924.1 | 23.7 | 1.25 |
| 4 (Frozen) | 1773.7 | 2.8 | 0.99 | 4614.99 | 0.5 | 1812.3 | 0.9787 | 1744.1 | 29.6 | 1.67 |
| Average value of $k$, $k_{avg}$ = | | | | | | | 0.9623 | | | |

Nomenclature:

$W_1$ = actual weight of fish (direct measurement)

$D_t$ = water tank diameter

$h$ = rise in the water level

ρ = density of fish from a particular sample = $\frac{4.W_1}{\pi.D_t^2.h}$

$a_i$ = length of horizontal scan

$b_i$ = length of vertical scan

$t$ = thickness of each line scan

$n$ = total number of scans

$V$ = Volume of fish = $\frac{\pi.t.}{4}\sum_{i=1}^{i=n} a_i.b_i$

$W_2$ = estimated weight of fish = $k.\rho.V$

$k$ = correction factor

$W_c$ = corrected weight of fish = $k_{avg}.W_2$

[1] Data used for the calculations are found in the appendix B.

Portions of any desired weight can be obtained in this manner simply by adding the estimated weight distribution data until the desired average weight per unit length is reached. The portioning resolution of this method will depend upon the spacing (or number) of scan lines. The smaller the scan spacing (more scan lines), the greater the portioning resolution. The same algorithm can be used for adjusting the blade spacing in the adjustable gap cutter arrangement.

### 6.2 Mechanical Properties of Salmon.

Experiments have also been conducted to determine the density, safe working load and Poisson's ratio for salmon. The density figures for salmon can be found in Table 6.1. The compression tests have revealed that it was possible to compress the fish by 0.5 to 1.5 cm (strain values of 0.18 to 0.20) . The corresponding stress values averaged at 11.0 to 13.8 kPa. Figure 6.2 shows the experimental setup used for this purpose. The Poisson's ratio for salmon was determined by carrying out a radial compression of 1.0 cm. As a result, about 0.1 to 0.2 cm increase of length was observed, which corresponds to a Poisson's ratio of 0.22 to 0.44.

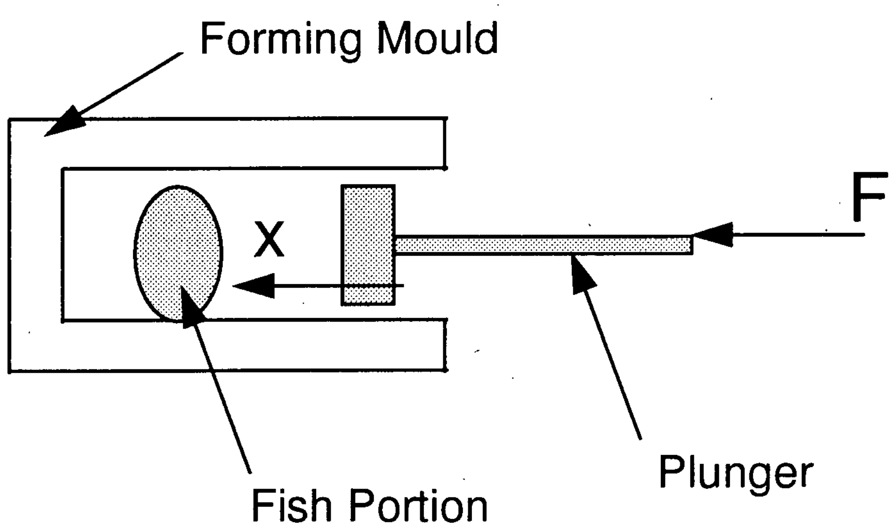



**Figure 6.2** An Experimental Setup for Determining Mechanical Parameters of Salmon.

These mechanical parameters would be used for determining allowable processing loads for fish so that the cutting and forming operations would not damage the quality of the meat.

### 6.3 Laboratory Prototype

A Laboratory prototype has been built for evaluating the performance of the proposed can filling system in forming and filling operations. A photograph of the experimental prototype is shown in Figure 6.3, It is a four degree of freedom system driven by three stepper motors and an electric solenoid. The detailed specifications of various components and the electronic control circuitry are presented in Appendix C. Although the design is slightly different from that of the proposed machine, the basic principle of operation is the same. The setup is operated by using a PC.

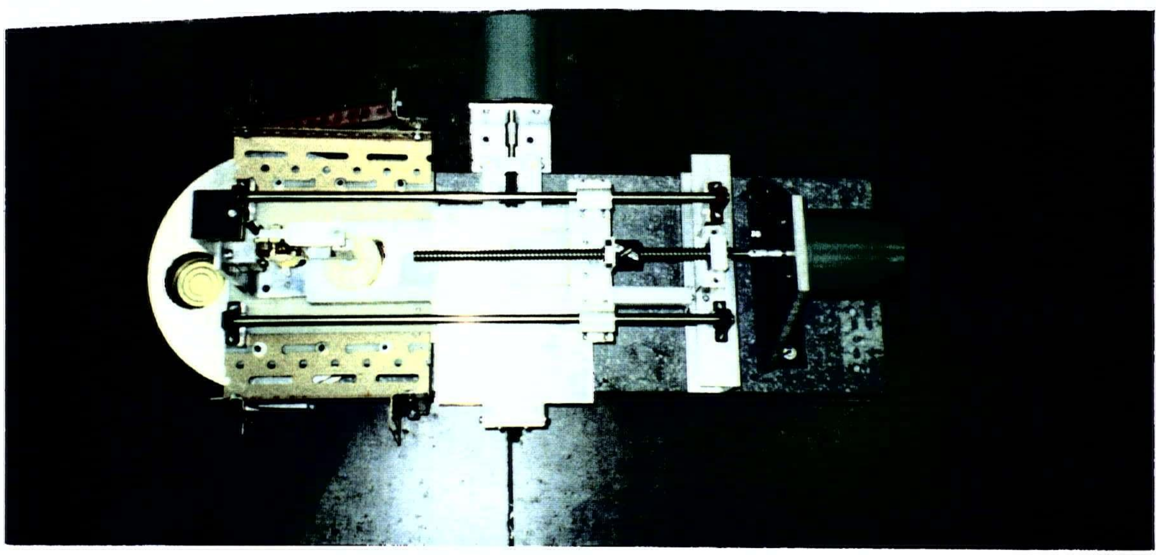


**Figure 6.3** Experimental Prototype for Evaluating the Filling and Forming Operations.

Figure 6.4 shows a schematic diagram of the system. To start with, the portions are placed on the lateral conveyor, which carries the portions in front of the fixed and movable half moulds. The movable half mould then carries the portions into the fixed half mould, and the portions are thus formed into the shape and size of the can. The rotary unit, carrying the cans, is then indexed so as to expose the formed portions to the corresponding cans passing underneath.

The filling plunger is then actuated to push the formed portions into the corresponding cans. This sequence is repeated to fill the desired number of cans.

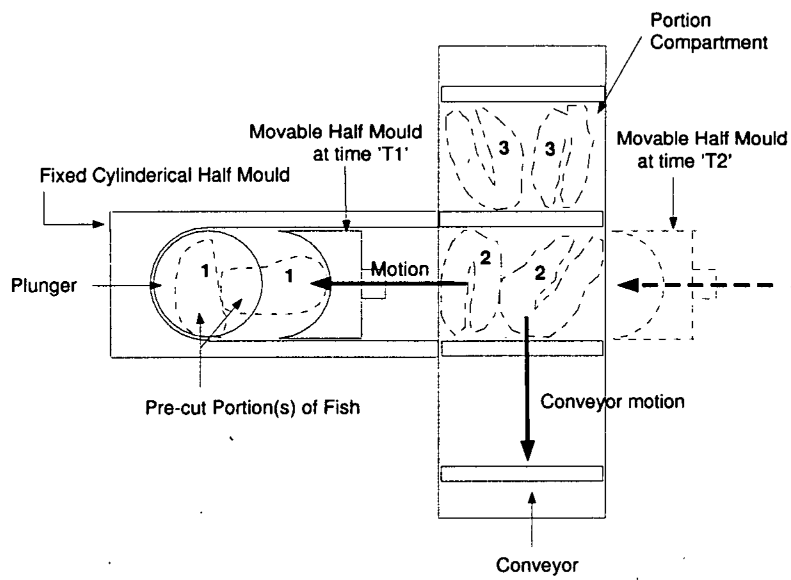



**Figure 6.4** Schematic Diagram of the Experimental Setup for Evaluating Forming and Filling Operations.

Two dozen portions of salmon were run in the machine and the following results were obtained:

Number of cross-packs = 4 (19.05 %)

Number of cans with skin / bones on flange top = 1 (4.76 %)

Number of correctly filled cans = 16 (76.19 %)

The remaining three portions were oversized and as a result jammed the machine. The reason for poor performance is excessive clearance between the moving parts. Had the clearance between the sliding parts been further reduced, the above defects could have been prevented. However, it can be concluded from the experiments that oversized portions would pose a problem during the forming and filling operations. One way to overcome this problem would be to slice-off the loosely hanging flaps around the fish belly, as indicated in figure 6.5. The meat removed in this manner can be used in the final weight compensation device. Size sorting (categorizing) of fish, for various can-sizes should be considered as a way of avoiding difficulties due to oversized portions.

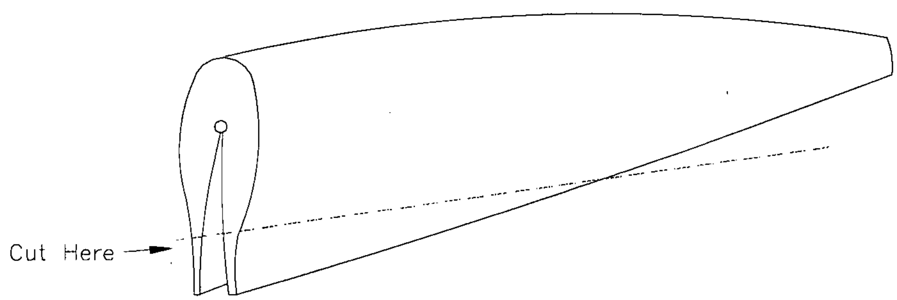



**Figure 6.5** Cutting the Loosely Hanging Flaps from the Fish Belly.

### 6.4 Scope of the Experiments

The scope of experimentation is determined by the extent to which the experimental setup conforms with the proposed final design. For example, the portion control experiments performed even with low resolution sensing of fish profiles have shown encouraging results. In the actual setup the use of line-scanning cameras or optical fibers is suggested, and hence a better performance would be expected. The laboratory prototype for the forming and filling operations was operated at considerably low speeds. When these operations are carried out at required industrial speeds (in fraction of a second), further degradation of performance may result. However, following system modifications are observed, which should be incorporated into the prototype.

- The fish should be sorted into various categories, based on their size. These categories may have some overlap between them. A category is assigned to each can size. The fish in assigned category would be chosen for filling cans of the corresponding size.

- The clearance between the sliding parts should be kept as small as possible.
- The use of an adjustable roof (cover plate) is recommended between the initial and final positions of the forming plunger. The height of the cover plate would be the same as the desired portion height ( = can height - head space). This arrangement would prevent the fish portions from flipping over by sudden impact of the forming plunger.
- To eliminate cross-packs, it is recommended that the loosely hanging flaps around the fish belly be sliced-off. The meat removed in this manner may be used in the final weight compensation device.

# Chapter 7

## Conclusions and Recommendations

In this concluding chapter, an overview of the research that has been carried out, is presented. Also, recommendations are made for possible future work.

### 7.1 An Overview of the Research

The existing can filling machinery, developed in 1930s, suffers from many drawbacks; e.g., low filling speed, excessive wastage of fish meat, poor product quality (presentation) and filling accuracy (underweight or overweight cans), and lack of adequate control action and flexibility. An automated can filling system is being developed from the conceptual stage that would eliminate or reduce the problems of existing can filling machinery, and would also satisfy the current industrial requirements. The major accomplishment of the research presented in this thesis are as follows:

1. An innovative weight based can-filling arrangement for salmon has been developed, starting from the conceptual stage and by studying alternative designs that would meet the industrial requirements.
2. New portioning and grouping techniques have been developed for the pre-filling stage using a weight-based portion control approach that would eliminate many of the shortcomings of the existing machinery. The results of preliminary experiments have shown that this approach could be employed in the proposed filling machine.
3. A general layout for the proposed filling machine has been developed, focusing on such features as versatility (processing flexibility), higher filling speed, improved product quality (presentation), and better weight control. Overall dimensions for various components have

been established. For example, the total floor space requirement for the filling machine is 12 m × 6m (approx.).

4. Various actuation and control requirements for the proposed system have been determined. An intermittent motion (geneva) mechanism has been designed for indexing the rotary unit of the filling machine. A 10 hp, 1200 rpm motor with 50:1 gear ratio would be needed to drive the rotary unit.
5. Laboratory experiments have been conducted to investigate the following aspects:
   - To determine mechanical properties of salmon; e.g., density, critical forming pressure, and Poisson's ratio. It has been found that salmon meat is incompressible. When subjected to excessive stresses and strains, the meat shears along the skin. Therefore, for the weight-based approach to work, it is recommended that the fish be sorted into various categories, based on their size. These categories may have some overlap between them. A category is assigned to each can size. The fish in assigned category would be chosen for filling cans of the corresponding size.
   - To determine length-weight correlation for salmon. The linear relation implies that the weight of fish can be estimated from its length.
   - To verify the weight-based geometric portioning technique presented in Chapter 4. The preliminary experimental results have been quite encouraging.
6. A laboratory prototype has been designed, built, and tested to check the performance of forming and filling operations under the proposed design conditions of the can filling system. Based on the drawbacks of the experimental setup, recommendations have been made for the actual prototype.
7. A cost-benefit evaluation has been carried out to determine the relative cost advantages of the proposed technology, when compared with the existing machines. By making some valid assumptions, it has been shown that the rate of return of the proposed machine is twice that of the existing machinery. Also, the proposed machine would completely pay for itself in two years.

Finally, it should be noted that the existing project was started with disorganized collection of information for an industry not much used to high-tech, and established procedures/methods. An attempt has been made to put together this information in an organized way, which others could use to develop the improved system. Although a number of illustrative examples have been given, but they are not necessarily the final solution.

## 7.2 Recommendations for Future Work

The scope of this research has been limited to the overall development of an automated can-filling system, focusing on the filling operations. The performance of the proposed design would depend to a large extent on the pre-filling operations. Portioning and grouping operations are the most critical activities in the overall canning process. Based on design assumptions and experimental results, the following suggestions are made for possible future work:

- To develop a fast and efficient portioning and grouping system for fish that would feed the filler at a rate of 500 portions per minute or faster.
- To develop a more complete working prototype for the filling machine based on the work presented in this thesis.
- To test the prototype under an actual industrial setting.
- To develop a post-filling inspection and repair workcell that would be compatible with the required filler speed.
- To integrate the filling subsystem into the pre-filling and post-filling subsystems. This would also involve design and implementation of a controller for the overall system.

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## Appendix A

### Experimental data for Length-weight Correlation of Salmon

This appendix presents the experimental data used for determining the length-weight correlation of Pink salmon. The length, width, thicknes and weight of the raw fish were measured, which were later fed to the iron-butcher for head, and gut removal. The weight and length of the resulting cannery dressed fish were then measured.

PINK MEASUREMENTS - ROUND/CANNERY BUTCHERED

| Sample Set | Date | Species | Area | Gear Type | Fish Wt @ Landing oz | Fish Length @ Landing cm | Fish Width @ Landing cm | Fish Thick @ Landing cm | Fish Wt @ Butcher oz | Fish Length @ Butcher cm |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Aug 15, 95 | P | Alaska | Seine | 71 | 50 | 14 | 5 | 48 | 38 |
| 1 | Aug 15, 95 | P | Alaska | Seine | 54 | 51 | 12 | 5 | 32 | 31.5 |
| 1 | Aug 15, 95 | P | Alaska | Seine | 52 | 53 | 11 | 5 | 28 | 29 |
| 1 | Aug 15, 95 | P | Alaska | Seine | 64 | 53 | 15 | 5.5 | 28 | 30 |
| 1 | Aug 15, 95 | P | Alaska | Seine | 51 | 54 | 11 | 5.5 | 32 | 31 |
| 1 | Aug 15, 95 | P | Alaska | Seine | 51 | 51 | 13 | 5 | 34 | 32 |
| 1 | Aug 15, 95 | P | Alaska | Seine | 55 | 54 | 12 | 6 | 21 | 28 |
| 1 | Aug 15, 95 | P | Alaska | Seine | 56 | 55 | 12.5 | 6 | 38 | 32 |
| 1 | Aug 15, 95 | P | Alaska | Seine | 55 | 52 | 12.5 | 5 | 22 | 28 |
| 1 | Aug 15, 95 | P | Alaska | Seine | 44 | 58 | 11.5 | 5 | 36 | 34 |
| 2 | Aug 15, 95 | P | Alaska | Seine | 55 | 52 | 12 | 5 | 28 | 31 |
| 2 | Aug 15, 95 | P | Alaska | Seine | 60 | 53 | 13 | 6 | 48 | 33 |
| 2 | Aug 15, 95 | P | Alaska | Seine | 66 | 55 | 14 | 5 | 46 | 33 |
| 2 | Aug 15, 95 | P | Alaska | Seine | 62 | 59 | 13 | 5 | 44 | 31 |
| 2 | Aug 15, 95 | P | Alaska | Seine | 67 | 59 | 15 | 6 | 42 | 35 |
| 2 | Aug 15, 95 | P | Alaska | Seine | 42 | 48 | 10 | 4 | 42 | 34 |
| 2 | Aug 15, 95 | P | Alaska | Seine | 60 | 56 | 13 | 5.5 | 42 | 37 |
| 2 | Aug 15, 95 | P | Alaska | Seine | 64 | 56 | 14 | 5 | 42 | 36 |
| 2 | Aug 15, 95 | P | Alaska | Seine | 67 | 58 | 13 | 5 | 38 | 36 |
| 2 | Aug 15, 95 | P | Alaska | Seine | 53 | 54 | 12 | 4 | 40 | 30 |
| 3 | Aug 15, 95 | P | Alaska | Seine | 52 | 56 | 11 | 4.5 | 32 | 30 |
| 3 | Aug 15, 95 | P | Alaska | Seine | 64 | 55 | 13 | 5 | 32 | 27.5 |
| 3 | Aug 15, 95 | P | Alaska | Seine | 56 | 54 | 11 | 4 | 34 | 35 |
| 3 | Aug 15, 95 | P | Alaska | Seine | 44 | 51 | 11 | 4 | 32 | 29.5 |
| 3 | Aug 15, 95 | P | Alaska | Seine | 55 | 52 | 12 | 4 | 46 | 34 |
| 3 | Aug 15, 95 | P | Alaska | Seine | 52 | 53 | 11.5 | 4.5 | 40 | 31 |
| 3 | Aug 15, 95 | P | Alaska | Seine | 44 | 53 | 10.5 | 4 | 34 | 33 |
| 3 | Aug 15, 95 | P | Alaska | Seine | 71 | 60 | 12.5 | 5 | 38 | 33.5 |
| 3 | Aug 15, 95 | P | Alaska | Seine | 46 | 49.5 | 11.5 | 4 | 48 | 37 |
| 3 | Aug 15, 95 | P | Alaska | Seine | 52 | 52 | 11.5 | 4 | 36 | 32 |
| 4 | Aug 15, 95 | P | Alaska | Seine | 46 | 53 | 11.5 | 4 | 36 | 31 |
| 4 | Aug 15, 95 | P | Alaska | Seine | 64 | 55 | 13 | 4.5 | 36 | 32 |
| 4 | Aug 15, 95 | P | Alaska | Seine | 54 | 53 | 12 | 4 | 46 | 36 |
| 4 | Aug 15, 95 | P | Alaska | Seine | 44 | 52 | 11 | 4 | 36 | 33 |
| 4 | Aug 15, 95 | P | Alaska | Seine | 54 | 52 | 12 | 4 | 32 | 30 |
| 4 | Aug 15, 95 | P | Alaska | Seine | 52 | 54 | 12 | 5 | 34 | 32 |
| 4 | Aug 15, 95 | P | Alaska | Seine | 54 | 51 | 11.5 | 3.5 | 32 | 30 |
| 4 | Aug 15, 95 | P | Alaska | Seine | 54 | 51.5 | 12 | 4.5 | 32 | 33.5 |
| 4 | Aug 15, 95 | P | Alaska | Seine | 50 | 52.5 | 11 | 4 | 38 | 32 |
| 4 | Aug 15, 95 | P | Alaska | Seine | 54 | 56 | 12 | 5 | 36 | 35 |
| 5 | Aug 15, 95 | P | Alaska | Seine | 50 | 54 | 11 | 4 | 34 | 32 |
| 5 | Aug 15, 95 | P | Alaska | Seine | 46 | 51 | 11.5 | 4 | 40 | 31 |
| 5 | Aug 15, 95 | P | Alaska | Seine | 50 | 52 | 12 | 4 | 34 | 31 |
| 5 | Aug 15, 95 | P | Alaska | Seine | 58 | 56 | 12 | 4.5 | 36 | 33 |
| 5 | Aug 15, 95 | P | Alaska | Seine | 60 | 54 | 11.5 | 4.5 | 32 | 31.5 |
| 5 | Aug 15, 95 | P | Alaska | Seine | 52 | 54 | 11 | 4.5 | 34 | 31 |
| 5 | Aug 15, 95 | P | Alaska | Seine | 56 | 54 | 11 | 4 | 34 | 32 |
| 5 | Aug 15, 95 | P | Alaska | Seine | 52 | 53 | 12 | 4 | 36 | 33 |
| 5 | Aug 15, 95 | P | Alaska | Seine | 48 | 53.5 | 11.5 | 3.5 | 36 | 32 |
| 5 | Aug 15, 95 | P | Alaska | Seine | 50 | 55 | 12 | 4.5 | 40 | 34 |
| 1 | Aug 16, 95 | P | | 3 Seine | 46 | 54 | 10 | 5 | 32 | 33.5 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 19 Aug 17, 95 P | Alaska | 52 | 52 | 11.5 | 5.5 | 28 | 30.5 |
| 19 Aug 17, 95 P | Alaska | 56 | 55 | 11 | 6 | 36 | 36 |
| 19 Aug 17, 95 P | Alaska | 60 | 55.5 | 11 | 6 | 34 | 31.5 |
| 19 Aug 17, 95 P | Alaska | 48 | 51 | 11 | 5.5 | 32 | 33 |
| 19 Aug 17, 95 P | Alaska | 44 | 51 | 11 | 6 | 32 | 32 |
| 19 Aug 17, 95 P | Alaska | 44 | 50.5 | 11 | 6 | 26 | 30 |
| 19 Aug 17, 95 P | Alaska | 48 | 53 | 10 | 6 | 32 | 34 |
| 19 Aug 17, 95 P | Alaska | 48 | 53 | 10 | 5.5 | 32 | 32.5 |
| 19 Aug 17, 95 P | Alaska | 46 | 51.5 | 10.5 | 5.5 | 38 | 36 |
| 20 Aug 17, 95 P | Alaska | 54 | 56 | 11 | 5.5 | 28 | 31 |
| 20 Aug 17, 95 P | Alaska | 52 | 54 | 11 | 6 | 32 | 34 |
| 20 Aug 17, 95 P | Alaska | 42 | 51.5 | 10 | 5 | 34 | 33 |
| 20 Aug 17, 95 P | Alaska | 46 | 51 | 11 | 5.5 | 32 | 31 |
| 20 Aug 17, 95 P | Alaska | 40 | 51 | 10 | 4.5 | 38 | 36 |
| 20 Aug 17, 95 P | Alaska | 50 | 54 | 11 | 6 | 26 | 30 |
| 20 Aug 17, 95 P | Alaska | 54 | 55.5 | 11 | 6 | 38 | 36 |
| 20 Aug 17, 95 P | Alaska | 62 | 56 | 12 | 6 | 28 | 31 |
| 20 Aug 17, 95 P | Alaska | 58 | 54 | 11 | 6 | 40 | 37 |
| 20 Aug 17, 95 P | Alaska | 42 | 50 | 10 | 5.5 | 34 | 34 |
| 21 Aug 17, 95 P | Alaska | 48 | 52 | 10 | 4.5 | 32 | 31 |
| 21 Aug 17, 95 P | Alaska | 54 | 55.5 | 10 | 5 | 34 | 34 |
| 21 Aug 17, 95 P | Alaska | 48 | 52 | 10 | 5 | 34 | 36 |
| 21 Aug 17, 95 P | Alaska | 48 | 52 | 10 | 4.5 | 36 | 36 |
| 21 Aug 17, 95 P | Alaska | 46 | 52 | 11 | 5 | 30 | 32 |
| 21 Aug 17, 95 P | Alaska | 56 | 55 | 10 | 5 | 28 | 32 |
| 21 Aug 17, 95 P | Alaska | 58 | 54 | 11 | 5 | 38 | 35.5 |
| 21 Aug 17, 95 P | Alaska | 56 | 54 | 11.5 | 5 | 38 | 34.5 |
| 21 Aug 17, 95 P | Alaska | 52 | 53 | 11 | 6 | 28 | 33 |
| 21 Aug 17, 95 P | Alaska | 52 | 53 | 10 | 5 | 34 | 32 |
| 22 Aug 17, 95 P | Alaska | 46 | 51 | 11 | 5 | 30 | 31 |
| 22 Aug 17, 95 P | Alaska | 68 | 57 | 13 | 6 | 44 | 36 |
| 22 Aug 17, 95 P | Alaska | 50 | 54 | 10 | 4.5 | 44 | 35 |
| 22 Aug 17, 95 P | Alaska | 50 | 52 | 11 | 5.5 | 30 | 33 |
| 22 Aug 17, 95 P | Alaska | 48 | 52 | 10 | 5 | 26 | 30 |
| 22 Aug 17, 95 P | Alaska | 54 | 54 | 10 | 6 | 44 | 35 |
| 22 Aug 17, 95 P | Alaska | 50 | 53 | 11 | 5.5 | 36 | 34 |
| 22 Aug 17, 95 P | Alaska | 66 | 55.5 | 12.5 | 6 | 28 | 31 |
| 22 Aug 17, 95 P | Alaska | 40 | 51 | 9.5 | 4.5 | 30 | 32.5 |
| 22 Aug 17, 95 P | Alaska | 68 | 57.5 | 11.5 | 5.5 | 32 | 30.5 |
| 23 Aug 17, 95 P | Alaska | 50 | 56 | 10 | 5.5 | 44 | 37 |
| 23 Aug 17, 95 P | Alaska | 54 | 55 | 11 | 5 | 40 | 34 |
| 23 Aug 17, 95 P | Alaska | 42 | 50 | 10 | 5 | 36 | 34 |
| 23 Aug 17, 95 P | Alaska | 68 | 59 | 12 | 6.5 | 36 | 34 |
| 23 Aug 17, 95 P | Alaska | 58 | 56 | 11.5 | 6 | 38 | 34 |
| 23 Aug 17, 95 P | Alaska | 52 | 53.5 | 11 | 5.5 | 36 | 35 |
| 23 Aug 17, 95 P | Alaska | 56 | 55.5 | 11 | 5.5 | 34 | 35 |
| 23 Aug 17, 95 P | Alaska | 46 | 52.5 | 11 | 5 | 30 | 32 |
| 23 Aug 17, 95 P | Alaska | 56 | 55 | 11 | 6 | 26 | 29 |
| 23 Aug 17, 95 P | Alaska | 50 | 56.5 | 11 | 5.5 | 32 | 35.5 |
| 24 Aug 17, 95 P | Alaska | 48 | 54 | 11 | 5.5 | 36 | 36 |
| 24 Aug 17, 95 P | Alaska | 42 | 50.5 | 10 | 5 | 36 | 36 |
| 24 Aug 17, 95 P | Alaska | 56 | 56 | 11 | 6 | 34 | 34 |
| 24 Aug 17, 95 P | Alaska | 56 | 55 | 10 | 5 | 30 | 32.5 |
| 24 Aug 17, 95 P | Alaska | 56 | 56 | 11.5 | 6 | 36 | 36 |
| 24 Aug 17, 95 P | Alaska | 50 | 52.5 | 11 | 5.5 | 32 | 31 |
| 24 Aug 17, 95 P | Alaska | 54 | 54.5 | 11.5 | 5.5 | 36 | 34.5 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2 Aug 17, 95 P | Alaska | 44 | 54 | 10 | 5 | 36 | 32.5 |
| 2 Aug 17, 95 P | Alaska | 54 | 54.5 | 11 | 6 | 34 | 34 |
| 2 Aug 17, 95 P | Alaska | 52 | 54 | 11 | 5.5 | 34 | 33.5 |
| 2 Aug 17, 95 P | Alaska | 56 | 56 | 11.5 | 6 | 42 | 37.5 |
| 2 Aug 17, 95 P | Alaska | 66 | 59 | 12 | 5.5 | 26 | 31 |
| 2 Aug 17, 95 P | Alaska | 48 | 52.5 | 9 | 5 | 32 | 34.5 |
| 2 Aug 17, 95 P | Alaska | 52 | 52.5 | 10 | 5 | 36 | 34 |
| 3 Aug 17, 95 P | Alaska | 44 | 59 | 10 | 5 | 32 | 35 |
| 3 Aug 17, 95 P | Alaska | 40 | 50 | 10 | 4.5 | 30 | 35 |
| 3 Aug 17, 95 P | Alaska | 62 | 57 | 11.5 | 6 | 40 | 37.5 |
| 3 Aug 17, 95 P | Alaska | 48 | 53.5 | 10 | 5 | 30 | 31.5 |
| 3 Aug 17, 95 P | Alaska | 48 | 54 | 9.5 | 5 | 26 | 31 |
| 3 Aug 17, 95 P | Alaska | 44 | 51 | 9 | 5 | 30 | 33.5 |
| 3 Aug 17, 95 P | Alaska | 50 | 53.5 | 10 | 6 | 36 | 34.5 |
| 3 Aug 17, 95 P | Alaska | 56 | 55.5 | 10 | 5.5 | 40 | 37 |
| 3 Aug 17, 95 P | Alaska | 56 | 57 | 11 | 5 | 26 | 30.5 |
| 3 Aug 17, 95 P | Alaska | 46 | 51 | 10 | 5 | 28 | 33.5 |
| 4 Aug 17, 95 P | Alaska | 38 | 50 | 9 | 4.5 | 36 | 35 |
| 4 Aug 17, 95 P | Alaska | 56 | 56 | 12 | 5 | 34 | 36.5 |
| 4 Aug 17, 95 P | Alaska | 66 | 61.5 | 11.5 | 6 | 36 | 38 |
| 4 Aug 17, 95 P | Alaska | 70 | 60 | 12 | 6 | 46 | 39 |
| 4 Aug 17, 95 P | Alaska | 54 | 55.5 | 10.5 | 5.5 | 40 | 38 |
| 4 Aug 17, 95 P | Alaska | 56 | 57 | 11.5 | 5 | 36 | 35 |
| 4 Aug 17, 95 P | Alaska | 60 | 57 | 11 | 6 | 44 | 39 |
| 4 Aug 17, 95 P | Alaska | 44 | 50.5 | 10 | 5 | 30 | 32 |
| 4 Aug 17, 95 P | Alaska | 54 | 55 | 11 | 5 | 32 | 32 |
| 4 Aug 17, 95 P | Alaska | 48 | 52 | 11 | 5 | 24 | 30 |
| 5 Aug 17, 95 P | Alaska | 54 | 54 | 11 | 5.5 | 38 | 37 |
| 5 Aug 17, 95 P | Alaska | 50 | 53.5 | 10 | 4 | 30 | 31 |
| 5 Aug 17, 95 P | Alaska | 62 | 57 | 11.5 | 6 | 34 | 32 |
| 5 Aug 17, 95 P | Alaska | 50 | 53 | 10.5 | 5.5 | 28 | 31.5 |
| 5 Aug 17, 95 P | Alaska | 44 | 51 | 10 | 5.5 | 32 | 33 |
| 5 Aug 17, 95 P | Alaska | 52 | 54.5 | 10 | 6 | 24 | 29.5 |
| 5 Aug 17, 95 P | Alaska | 48 | 53.5 | 10 | 5 | 30 | 32 |
| 5 Aug 17, 95 P | Alaska | 42 | 50 | 10 | 5 | 32 | 34.5 |
| 5 Aug 17, 95 P | Alaska | 52 | 54.5 | 11 | 6 | 32 | 33.5 |
| 5 Aug 17, 95 P | Alaska | 36 | 52 | 9.5 | 4.5 | 34 | 33 |
| 6 Aug 17, 95 P | Alaska | 52 | 55 | 11.5 | 5 | 28 | 30 |
| 6 Aug 17, 95 P | Alaska | 56 | 54.5 | 11 | 5.5 | 34 | 33.5 |
| 6 Aug 17, 95 P | Alaska | 32 | 48 | 9.5 | 4.5 | 48 | 37 |
| 6 Aug 17, 95 P | Alaska | 70 | 61 | 13 | 6.5 | 40 | 35.5 |
| 6 Aug 17, 95 P | Alaska | 18 | 54 | 11 | 4 | 24 | 29 |
| 6 Aug 17, 95 P | Alaska | 54 | 55.5 | 10 | 5 | 32 | 32 |
| 6 Aug 17, 95 P | Alaska | 56 | 56 | 10 | 5.5 | 38 | 33 |
| 6 Aug 17, 95 P | Alaska | 56 | 56 | 11 | 5.5 | 40 | 35 |
| 6 Aug 17, 95 P | Alaska | 44 | 52 | 10.5 | 5 | 36 | 34 |
| 6 Aug 17, 95 P | Alaska | 60 | 55.5 | 11.5 | 6 | 36 | 34 |
| 7 Aug 17, 95 P | Alaska | 48 | 50 | 10.5 | 5.5 | 36 | 35 |
| 7 Aug 17, 95 P | Alaska | 46 | 52 | 10 | 5 | 36 | 33 |
| 7 Aug 17, 95 P | Alaska | 48 | 57 | 10 | 5 | 32 | 32 |
| 7 Aug 17, 95 P | Alaska | 48 | 54 | 10.5 | 5 | 40 | 33.5 |
| 7 Aug 17, 95 P | Alaska | 46 | 52 | 11 | 5 | 34 | 34 |
| 7 Aug 17, 95 P | Alaska | 54 | 54 | 10.5 | 5.5 | 32 | 33 |
| 7 Aug 17, 95 P | Alaska | 56 | 52 | 12 | 5.5 | 32 | 30 |
| 7 Aug 17, 95 P | Alaska | 58 | 56.5 | 11.5 | 6 | 32 | 33.5 |
| 7 Aug 17, 95 P | Alaska | 50 | 55 | 11 | 6 | 30 | 30.5 |

MEASUREMENTS - ROUND/CANNERY BUTCHERED

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Aug 16, 95 | P | | 3 | Seine | 56 | 53.5 | 11.5 | 3.5 | 34 | 33 |
| 1 | Aug 16, 95 | P | | 3 | Seine | 66 | 57 | 14 | 4 | 38 | 36 |
| 1 | Aug 16, 95 | P | | 3 | Seine | 56 | 54 | 12 | 3.5 | 38 | 35.5 |
| 2 | Aug 16, 95 | P | | 3 | Seine | 52 | 55 | 12 | 3.5 | 32 | 33 |
| 2 | Aug 16, 95 | P | | 3 | Seine | 70 | 68 | 14.5 | 4 | 34 | 33 |
| 2 | Aug 16, 95 | P | | 3 | Seine | 62 | 56 | 12.5 | 4.5 | 42 | 35 |
| 2 | Aug 16, 95 | P | | 3 | Seine | 50 | 52 | 12 | 3.5 | 30 | 30 |
| 2 | Aug 16, 95 | P | | 3 | Seine | 50 | 53 | 12.5 | 3.5 | 48 | 37 |
| 2 | Aug 16, 95 | P | | 3 | Seine | 58 | 56 | 12.5 | 4 | 38 | 34 |
| 2 | Aug 16, 95 | P | | 3 | Seine | 58 | 55.5 | 12 | 4 | 40 | 35 |
| 2 | Aug 16, 95 | P | | 3 | Seine | 58 | 56 | 12 | 4.5 | 36 | 33 |
| 2 | Aug 16, 95 | P | | 3 | Seine | 70 | 56.5 | 14 | 4 | 32 | 32 |
| 2 | Aug 16, 95 | P | | 3 | Seine | 54 | 54.5 | 11 | 3.5 | 44 | 35.5 |
| 3 | Aug 16, 95 | P | | 3 | Seine | 50 | 55 | 11 | 3.5 | 44 | 30 |
| 3 | Aug 16, 95 | P | | 3 | Seine | 54 | 53.5 | 11.5 | 3.5 | 48 | 40 |
| 3 | Aug 16, 95 | P | | 3 | Seine | 70 | 60 | 13 | 4 | 32 | 31.5 |
| 3 | Aug 16, 95 | P | | 3 | Seine | 52 | 52 | 11.5 | 3 | 32 | 32 |
| 3 | Aug 16, 95 | P | | 3 | Seine | 48 | 52 | 11 | 3 | 36 | 34.5 |
| 3 | Aug 16, 95 | P | | 3 | Seine | 44 | 52 | 10 | 3 | 32 | 33 |
| 3 | Aug 16, 95 | P | | 3 | Seine | 58 | 52 | 12 | 4 | 38 | 34.5 |
| 3 | Aug 16, 95 | P | | 3 | Seine | 50 | 50.5 | 11 | 3.5 | 34 | 31.5 |
| 3 | Aug 16, 95 | P | | 3 | Seine | 58 | 56 | 11.5 | 3 | 36 | 35 |
| 3 | Aug 16, 95 | P | | 3 | Seine | 50 | 54 | 10.5 | 3 | 28 | 32 |
| 4 | Aug 16, 95 | P | | 3 | Seine | 56 | 56 | 11 | 4 | 36 | 35 |
| 4 | Aug 16, 95 | P | | 3 | Seine | 66 | 58 | 13 | 4.5 | 30 | 33.5 |
| 4 | Aug 16, 95 | P | | 3 | Seine | 48 | 50 | 9.5 | 3 | 40 | 34.5 |
| 4 | Aug 16, 95 | P | | 3 | Seine | 52 | 54 | 11 | 3.5 | 44 | 32 |
| 4 | Aug 16, 95 | P | | 3 | Seine | 50 | 54 | 12 | 3.5 | 44 | 37 |
| 4 | Aug 16, 95 | P | | 3 | Seine | 60 | 55 | 12 | 4 | 30 | 31 |
| 4 | Aug 16, 95 | P | | 3 | Seine | 56 | 54 | 10.5 | 3.5 | 34 | 35 |
| 4 | Aug 16, 95 | P | | 3 | Seine | 46 | 52 | 10 | 3 | 36 | 36 |
| 4 | Aug 16, 95 | P | | 3 | Seine | 44 | 50 | 10 | 3 | 28 | 30 |
| 4 | Aug 16, 95 | P | | 3 | Seine | 70 | 55 | 13 | 5 | 42 | 36.5 |
| 5 | Aug 16, 95 | P | | 3 | Seine | 64 | 57 | 13 | 5.5 | 42 | 34 |
| 5 | Aug 16, 95 | P | | 3 | Seine | 54 | 55 | 11 | 5 | 34 | 34 |
| 5 | Aug 16, 95 | P | | 3 | Seine | 54 | 57 | 11 | 5 | 36 | 34 |
| 5 | Aug 16, 95 | P | | 3 | Seine | 58 | 55.5 | 10 | 5 | 44 | 35.5 |
| 5 | Aug 16, 95 | P | | 3 | Seine | 46 | 54 | 9.5 | 5.5 | 38 | 35 |
| 5 | Aug 16, 95 | P | | 3 | Seine | 48 | 53 | 9.5 | 5 | 38 | 34.5 |
| 5 | Aug 16, 95 | P | | 3 | Seine | 54 | 56 | 11 | 5 | 30 | 32 |
| 5 | Aug 16, 95 | P | | 3 | Seine | 30 | 48 | 7.5 | 4 | 38 | 35.5 |
| 5 | Aug 16, 95 | P | | 3 | Seine | 52 | 54 | 10 | 5 | 30 | 32.5 |
| 5 | Aug 16, 95 | P | | 3 | Seine | 66 | 57 | 12 | 6 | 18 | 26 |
| 1 | Aug 17, 95 | P | Alaska | | | 44 | 52 | 10 | 5 | 46 | 34 |
| 1 | Aug 17, 95 | P | Alaska | | | 46 | 52.5 | 10 | 5 | 30 | 34 |
| 1 | Aug 17, 95 | P | Alaska | | | 56 | 56 | 10 | 5 | 38 | 36 |
| 1 | Aug 17, 95 | P | Alaska | | | 60 | 59.5 | 12 | 6 | 34 | 37 |
| 1 | Aug 17, 95 | P | Alaska | | | 42 | 51 | 10 | 5 | 30 | 33 |
| 1 | Aug 17, 95 | P | Alaska | | | 48 | 52.5 | 10 | 5.5 | 30 | 33.5 |
| 1 | Aug 17, 95 | P | Alaska | | | 50 | 53 | 10 | 5 | 36 | 35 |
| 1 | Aug 17, 95 | P | Alaska | | | 54 | 56 | 10 | 5 | 30 | 34.5 |
| 1 | Aug 17, 95 | P | Alaska | | | 56 | 55.5 | 11 | 5.5 | 28 | 34 |
| 1 | Aug 17, 95 | P | Alaska | | | 58 | 57 | 12 | 6 | 34 | 36 |
| 2 | Aug 17, 95 | P | Alaska | | | 66 | 59 | 11 | 6 | 30 | 33 |
| 2 | Aug 17, 95 | P | Alaska | | | 56 | 55 | 11 | 5 | 40 | 37 |
| 2 | Aug 17, 95 | P | Alaska | | | 50 | 54 | 10.5 | 4 | 34 | 32 |

MEASUREMENTS - ROUND/CANNERY BUTCHERED

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Aug 16, 95 | P | 3 | Seine | 54 | 53 | 10 | 5 | 32 | 33 |
| 1 | Aug 16, 95 | P | 3 | Seine | 62 | 57 | 11 | 5.5 | 48 | 39 |
| 1 | Aug 16, 95 | P | 3 | Seine | 48 | 52 | 9 | 4.5 | 52 | 35 |
| 1 | Aug 16, 95 | P | 3 | Seine | 56 | 55 | 11 | 5.5 | 32 | 32 |
| 1 | Aug 16, 95 | P | 3 | Seine | 46 | 51 | 9.5 | 4.5 | 44 | 38 |
| 1 | Aug 16, 95 | P | 3 | Seine | 70 | 59 | 12.5 | 6 | 38 | 35 |
| 1 | Aug 16, 95 | P | 3 | Seine | 56 | 55 | 10 | 5 | 30 | 33.5 |
| 1 | Aug 16, 95 | P | 3 | Seine | 48 | 53 | 10 | 5 | 32 | 32 |
| 1 | Aug 16, 95 | P | 3 | Seine | 58 | 55.5 | 11 | 6 | 38 | 35.5 |
| 2 | Aug 16, 95 | P | 3 | Seine | 56 | 54 | 11 | 5.5 | 36 | 35 |
| 2 | Aug 16, 95 | P | 3 | Seine | 48 | 52 | 10 | 5 | 42 | 35 |
| 2 | Aug 16, 95 | P | 3 | Seine | 62 | 57.5 | 12 | 5 | 32 | 33 |
| 2 | Aug 16, 95 | P | 3 | Seine | 52 | 52 | 11 | 5 | 42 | 38.5 |
| 2 | Aug 16, 95 | P | 3 | Seine | 52 | 54 | 11 | 5.5 | 42 | 38 |
| 2 | Aug 16, 95 | P | 3 | Seine | 62 | 55 | 13 | 5 | 28 | 31 |
| 2 | Aug 16, 95 | P | 3 | Seine | 44 | 52.5 | 10 | 5 | 40 | 36 |
| 2 | Aug 16, 95 | P | 3 | Seine | 68 | 60 | 13 | 5.5 | 40 | 36 |
| 2 | Aug 16, 95 | P | 3 | Seine | 68 | 56.5 | 11 | 6 | 34 | 33.5 |
| 2 | Aug 16, 95 | P | 3 | Seine | 64 | 56.5 | 12 | 6.5 | 34 | 33 |
| 3 | Aug 16, 95 | P | 3 | Seine | 54 | 54 | 11 | 4.5 | 32 | 32 |
| 3 | Aug 16, 95 | P | 3 | Seine | 58 | 53.5 | 11 | 5.5 | 30 | 31 |
| 3 | Aug 16, 95 | P | 3 | Seine | 80 | 61 | 14 | 6 | 42 | 37 |
| 3 | Aug 16, 95 | P | 3 | Seine | 48 | 50 | 11 | 5 | 30 | 35 |
| 3 | Aug 16, 95 | P | 3 | Seine | 62 | 58 | 12 | 6 | 52 | 40 |
| 3 | Aug 16, 95 | P | 3 | Seine | 60 | 54 | 11.5 | 5.5 | 36 | 33 |
| 3 | Aug 16, 95 | P | 3 | Seine | 58 | 55 | 11.5 | 5.5 | 36 | 35 |
| 3 | Aug 16, 95 | P | 3 | Seine | 52 | 55 | 10 | 5 | 36 | 34.5 |
| 3 | Aug 16, 95 | P | 3 | Seine | 68 | 57.5 | 12 | 6.5 | 40 | 35.5 |
| 3 | Aug 16, 95 | P | 3 | Seine | 50 | 51 | 10 | 6 | 36 | 34 |
| 4 | Aug 16, 95 | P | 3 | Seine | 46 | 49.5 | 10 | 5 | 38 | 38 |
| 4 | Aug 16, 95 | P | 3 | Seine | 64 | 55.5 | 12 | 5.5 | 12 | 22 |
| 4 | Aug 16, 95 | P | 3 | Seine | 60 | 55.5 | 11 | 5.5 | 40 | 34 |
| 4 | Aug 16, 95 | P | 3 | Seine | 56 | 55.5 | 11 | 5.5 | 30 | 32 |
| 4 | Aug 16, 95 | P | 3 | Seine | 56 | 52 | 10.5 | 6 | 32 | 34 |
| 4 | Aug 16, 95 | P | 3 | Seine | 64 | 56 | 12.5 | 5 | 38 | 35 |
| 4 | Aug 16, 95 | P | 3 | Seine | 50 | 51.5 | 11 | 5 | 30 | 32 |
| 4 | Aug 16, 95 | P | 3 | Seine | 50 | 51.5 | 11 | 4.5 | 32 | 31.5 |
| 4 | Aug 16, 95 | P | 3 | Seine | 48 | 52 | 10 | 5 | 32 | 33 |
| 4 | Aug 16, 95 | P | 3 | Seine | 22 | 41 | 7.5 | 3.5 | 36 | 35 |
| 5 | Aug 16, 95 | P | 3 | Seine | 62 | 54.5 | 11.5 | 5 | 28 | 29 |
| 5 | Aug 16, 95 | P | 3 | Seine | 56 | 55 | 11 | 6 | 36 | 35 |
| 5 | Aug 16, 95 | P | 3 | Seine | 60 | 55 | 11.5 | 6 | 34 | 34 |
| 5 | Aug 16, 95 | P | 3 | Seine | 56 | 52 | 12 | 5.5 | 40 | 36 |
| 5 | Aug 16, 95 | P | 3 | Seine | 78 | 60 | 13.5 | 6 | 36 | 33.5 |
| 5 | Aug 16, 95 | P | 3 | Seine | 40 | 48.5 | 9.5 | 5 | 42 | 38 |
| 5 | Aug 16, 95 | P | 3 | Seine | 64 | 60 | 11.5 | 6 | 50 | 37.5 |
| 5 | Aug 16, 95 | P | 3 | Seine | 62 | 55 | 12 | 5.5 | 40 | 35 |
| 5 | Aug 16, 95 | P | 3 | Seine | 46 | 50 | 10 | 4.5 | 34 | 32.5 |
| 5 | Aug 16, 95 | P | 3 | Seine | 50 | 53 | 10.5 | 5.5 | 28 | 31.5 |
| 1 | Aug 16, 95 | P | 3 | Seine | 50 | 53 | 11 | 4.5 | 34 | 35.5 |
| 1 | Aug 16, 95 | P | 3 | Seine | 44 | 51 | 10.5 | 3.5 | 44 | 36 |
| 1 | Aug 16, 95 | P | 3 | Seine | 52 | 53 | 12 | 4 | 34 | 32.5 |
| 1 | Aug 16, 95 | P | 3 | Seine | 62 | 57 | 12 | 4 | 40 | 37.5 |
| 1 | Aug 16, 95 | P | 3 | Seine | 54 | 53 | 12 | 3.5 | 32 | 32.5 |
| 1 | Aug 16, 95 | P | 3 | Seine | 52 | 52 | 11 | 3.5 | 30 | 31.5 |
| 1 | Aug 16, 95 | P | 3 | Seine | 60 | 54.5 | 12 | 3.5 | 36 | 34 |

MEASUREMENTS - ROUND/CANNERY BUTCHERED

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 13 | Aug 17, 95 | P | Alaska | 50 | 53.5 | 10 | 6 | 36 | 33 |
| 13 | Aug 17, 95 | P | Alaska | 60 | 57.5 | 12 | 6.5 | 36 | 35 |
| 13 | Aug 17, 95 | P | Alaska | 54 | 53.5 | 11 | 5.5 | 34 | 31 |
| 13 | Aug 17, 95 | P | Alaska | 46 | 52.5 | 11 | 6 | 30 | 32 |
| 13 | Aug 17, 95 | P | Alaska | 44 | 51 | 10 | 5 | 32 | 33.5 |
| 14 | Aug 17, 95 | P | Alaska | 80 | 64.5 | 14 | 7 | 56 | 40 |
| 14 | Aug 17, 95 | P | Alaska | 54 | 55.5 | 11.5 | 6 | 40 | 35 |
| 14 | Aug 17, 95 | P | Alaska | 44 | 52 | 10 | 5.5 | 36 | 36 |
| 14 | Aug 17, 95 | P | Alaska | 60 | 57 | 12.5 | 6.5 | 30 | 34 |
| 14 | Aug 17, 95 | P | Alaska | 54 | 53 | 11 | 6 | 34 | 35 |
| 14 | Aug 17, 95 | P | Alaska | 56 | 55 | 11.5 | 6 | 34 | 34.5 |
| 14 | Aug 17, 95 | P | Alaska | 46 | 53 | 11 | 5.5 | 38 | 34 |
| 14 | Aug 17, 95 | P | Alaska | 48 | 54 | 10.5 | 5 | 30 | 33 |
| 14 | Aug 17, 95 | P | Alaska | 54 | 54 | 11.5 | 6 | 28 | 32 |
| 14 | Aug 17, 95 | P | Alaska | 44 | 53 | 10 | 5.5 | 34 | 33 |
| 15 | Aug 17, 95 | P | Alaska | 54 | 54 | 12 | 6 | 36 | 34 |
| 15 | Aug 17, 95 | P | Alaska | 58 | 56 | 12 | 6 | 40 | 37.5 |
| 15 | Aug 17, 95 | P | Alaska | 50 | 53.5 | 11.5 | 5.5 | 30 | 33 |
| 15 | Aug 17, 95 | P | Alaska | 68 | 59.5 | 13 | 7 | 28 | 32.5 |
| 15 | Aug 17, 95 | P | Alaska | 44 | 53 | 10 | 5 | 46 | 37 |
| 15 | Aug 17, 95 | P | Alaska | 60 | 55 | 11.5 | 6 | 34 | 33 |
| 15 | Aug 17, 95 | P | Alaska | 54 | 55 | 12 | 6.5 | 32 | 34 |
| 15 | Aug 17, 95 | P | Alaska | 58 | 56.5 | 11.5 | 6 | 38 | 35 |
| 15 | Aug 17, 95 | P | Alaska | 44 | 53 | 10 | 5 | 36 | 33.5 |
| 15 | Aug 17, 95 | P | Alaska | 50 | 52.5 | 10.5 | 5.5 | 40 | 37 |
| 16 | Aug 17, 95 | P | Alaska | 58 | 55 | 11 | 5 | 36 | 35 |
| 16 | Aug 17, 95 | P | Alaska | 52 | 51.5 | 10.5 | 5.5 | 50 | 32 |
| 16 | Aug 17, 95 | P | Alaska | 50 | 54.5 | 11 | 5 | 32 | 33 |
| 16 | Aug 17, 95 | P | Alaska | 58 | 55 | 11 | 5.5 | 44 | 37 |
| 16 | Aug 17, 95 | P | Alaska | 44 | 51.5 | 10 | 4.5 | 28 | 30 |
| 16 | Aug 17, 95 | P | Alaska | 68 | 59 | 11.5 | 6 | 32 | 33 |
| 16 | Aug 17, 95 | P | Alaska | 48 | 53 | 11 | 5.5 | 38 | 34 |
| 16 | Aug 17, 95 | P | Alaska | 52 | 53.5 | 10 | 6 | 30 | 31 |
| 16 | Aug 17, 95 | P | Alaska | 58 | 57.5 | 11 | 6.5 | 38 | 36 |
| 16 | Aug 17, 95 | P | Alaska | 64 | 58 | 12 | 6 | 40 | 37 |
| 17 | Aug 17, 95 | P | Alaska | 52 | 55 | 11 | 6 | 46 | 36 |
| 17 | Aug 17, 95 | P | Alaska | 48 | 53.5 | 10.5 | 5 | 28 | 31 |
| 17 | Aug 17, 95 | P | Alaska | 44 | 50.5 | 10.5 | 5 | 40 | 37 |
| 17 | Aug 17, 95 | P | Alaska | 52 | 55 | 10.5 | 5.5 | 32 | 32 |
| 17 | Aug 17, 95 | P | Alaska | 66 | 59.5 | 12 | 6 | 36 | 34.5 |
| 17 | Aug 17, 95 | P | Alaska | 60 | 59 | 12 | 6.5 | 34 | 34 |
| 17 | Aug 17, 95 | P | Alaska | 56 | 56.5 | 11 | 5 | 40 | 37 |
| 17 | Aug 17, 95 | P | Alaska | 40 | 50 | 10 | 5 | 26 | 31 |
| 17 | Aug 17, 95 | P | Alaska | 48 | 52 | 10.5 | 5.5 | 40 | 37 |
| 17 | Aug 17, 95 | P | Alaska | 60 | 54.5 | 13 | 6 | 32 | 31 |
| 18 | Aug 17, 95 | P | Alaska | 56 | 53 | 12 | 5 | 30 | 32 |
| 18 | Aug 17, 95 | P | Alaska | 58 | 57 | 11.5 | 6 | 32 | 33 |
| 18 | Aug 17, 95 | P | Alaska | 52 | 54 | 11 | 6 | 38 | 36 |
| 18 | Aug 17, 95 | P | Alaska | 32 | 49.5 | 9 | 5 | 58 | 42 |
| 18 | Aug 17, 95 | P | Alaska | 48 | 52 | 11 | 5.5 | 32 | 31 |
| 18 | Aug 17, 95 | P | Alaska | 84 | 62.5 | 14 | 7.5 | 34 | 34 |
| 18 | Aug 17, 95 | P | Alaska | 52 | 53.5 | 11 | 5.5 | 30 | 31 |
| 18 | Aug 17, 95 | P | Alaska | 38 | 51 | 9.5 | 5 | 24 | 30 |
| 18 | Aug 17, 95 | P | Alaska | 48 | 51 | 11 | 5.5 | 34 | 32 |
| 18 | Aug 17, 95 | P | Alaska | 50 | 54 | 11 | 5.5 | 20 | 27.5 |
| 19 | Aug 17, 95 | P | Alaska | 50 | 54.5 | 11 | 5 | 28 | 31 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 7 | Aug 17, 95 | P | Alaska | 60 | 57 | 12 | 6 | 36 | 32.5 |
| 8 | Aug 17, 95 | P | Alaska | 52 | 53.5 | 10.5 | 4.5 | 42 | 35 |
| 8 | Aug 17, 95 | P | Alaska | 62 | 56.5 | 11 | 6 | 30 | 35 |
| 8 | Aug 17, 95 | P | Alaska | 66 | 59 | 12 | 5 | 32 | 34 |
| 8 | Aug 17, 95 | P | Alaska | 50 | 52.5 | 10 | 5 | 32 | 35 |
| 8 | Aug 17, 95 | P | Alaska | 44 | 52 | 10 | 5.5 | 40 | 36 |
| 8 | Aug 17, 95 | P | Alaska | 54 | 54.5 | 11 | 5.5 | 30 | 32 |
| 8 | Aug 17, 95 | P | Alaska | 58 | 56.5 | 11 | 5.5 | 36 | 36 |
| 8 | Aug 17, 95 | P | Alaska | 48 | 53 | 10 | 5 | 36 | 36 |
| 8 | Aug 17, 95 | P | Alaska | 48 | 52.5 | 10 | 5.5 | 34 | 34 |
| 8 | Aug 17, 95 | P | Alaska | 52 | 55 | 10.5 | 5.5 | 32 | 33 |
| 9 | Aug 17, 95 | P | Alaska | 48 | 51 | 10 | 5 | 46 | 36 |
| 9 | Aug 17, 95 | P | Alaska | 56 | 54 | 11 | 6 | 38 | 34 |
| 9 | Aug 17, 95 | P | Alaska | 56 | 55.5 | 11.5 | 6 | 34 | 34 |
| 9 | Aug 17, 95 | P | Alaska | 54 | 54 | 11 | 6 | 34 | 33.5 |
| 9 | Aug 17, 95 | P | Alaska | 68 | 58 | 12 | 7 | 40 | 35 |
| 9 | Aug 17, 95 | P | Alaska | 50 | 56 | 11 | 5 | 30 | 31 |
| 9 | Aug 17, 95 | P | Alaska | 62 | 56 | 11 | 5.5 | 42 | 36 |
| 9 | Aug 17, 95 | P | Alaska | 46 | 52 | 10 | 5 | 36 | 34 |
| 9 | Aug 17, 95 | P | Alaska | 52 | 52.5 | 10.5 | 6 | 28 | 31 |
| 9 | Aug 17, 95 | P | Alaska | 64 | 58.5 | 12 | 6 | 32 | 32.5 |
| 10 | Aug 17, 95 | P | Alaska | 48 | 54 | 10 | 5.5 | 32 | 34 |
| 10 | Aug 17, 95 | P | Alaska | 50 | 55 | 10 | 5 | 30 | 32 |
| 10 | Aug 17, 95 | P | Alaska | 54 | 55 | 11 | 5 | 34 | 33 |
| 10 | Aug 17, 95 | P | Alaska | 58 | 56 | 11 | 6 | 44 | 36 |
| 10 | Aug 17, 95 | P | Alaska | 64 | 57.5 | 12 | 5.5 | 36 | 35 |
| 10 | Aug 17, 95 | P | Alaska | 52 | 54.5 | 10 | 6 | 32 | 32 |
| 10 | Aug 17, 95 | P | Alaska | 46 | 53.5 | 10 | 5 | 34 | 31 |
| 10 | Aug 17, 95 | P | Alaska | 54 | 52 | 11 | 6 | 26 | 32.5 |
| 10 | Aug 17, 95 | P | Alaska | 52 | 54 | 12 | 6 | 32 | 33.5 |
| 10 | Aug 17, 95 | P | Alaska | 54 | 54.5 | 11 | 6 | 32 | 31 |
| 11 | Aug 17, 95 | P | Alaska | 48 | 53 | 10 | 6 | 32 | 33.5 |
| 11 | Aug 17, 95 | P | Alaska | 48 | 53 | 10 | 5.5 | 30 | 30 |
| 11 | Aug 17, 95 | P | Alaska | 44 | 52.5 | 10 | 5 | 28 | 32 |
| 11 | Aug 17, 95 | P | Alaska | 66 | 59.5 | 12 | 6 | 46 | 36 |
| 11 | Aug 17, 95 | P | Alaska | 44 | 53 | 10 | 5 | 26 | 29.5 |
| 11 | Aug 17, 95 | P | Alaska | 50 | 53 | 11 | 5.5 | 32 | 34 |
| 11 | Aug 17, 95 | P | Alaska | 42 | 51 | 10 | 5 | 36 | 35 |
| 11 | Aug 17, 95 | P | Alaska | 50 | 53 | 11 | 5.5 | 34 | 33 |
| 11 | Aug 17, 95 | P | Alaska | 50 | 54 | 10.5 | 5.5 | 32 | 32.5 |
| 11 | Aug 17, 95 | P | Alaska | 54 | 54 | 11 | 6.5 | 32 | 32.5 |
| 12 | Aug 17, 95 | P | Alaska | 36 | 48 | 10.5 | 5.5 | 46 | 37 |
| 12 | Aug 17, 95 | P | Alaska | 58 | 55.5 | 11 | 6 | 32 | 33 |
| 12 | Aug 17, 95 | P | Alaska | 50 | 53 | 11 | 5.5 | 34 | 33 |
| 12 | Aug 17, 95 | P | Alaska | 46 | 52.5 | 10.5 | 5.5 | 36 | 34 |
| 12 | Aug 17, 95 | P | Alaska | 54 | 54 | 11 | 6.5 | 40 | 34 |
| 12 | Aug 17, 95 | P | Alaska | 70 | 58.5 | 12.5 | 7 | 22 | 27.5 |
| 12 | Aug 17, 95 | P | Alaska | 50 | 54.5 | 10 | 5.5 | 40 | 36.5 |
| 12 | Aug 17, 95 | P | Alaska | 62 | 57 | 12 | 6 | 30 | 31 |
| 12 | Aug 17, 95 | P | Alaska | 52 | 55 | 11 | 5.5 | 30 | 32 |
| 12 | Aug 17, 95 | P | Alaska | 50 | 53 | 10 | 5.5 | 34 | 32.5 |
| 13 | Aug 17, 95 | P | Alaska | 58 | 56 | 12 | 6 | 40 | 35 |
| 13 | Aug 17, 95 | P | Alaska | 68 | 60.5 | 13 | 7 | 44 | 36.5 |
| 13 | Aug 17, 95 | P | Alaska | 64 | 56.5 | 12 | 7 | 44 | 36.5 |
| 13 | Aug 17, 95 | P | Alaska | 50 | 53 | 11 | 5.5 | 34 | 33.5 |
| 13 | Aug 17, 95 | P | Alaska | 54 | 55.5 | 11 | 6.5 | 40 | 36.5 |

,EASUREMENTS - ROUND/CANNERY BUTCHERED

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 24 | Aug 17, 95 | P | Alaska | 54 | 54 | 11 | 5.5 | 34 | 34 |
| 24 | Aug 17, 95 | P | Alaska | 56 | 55.5 | 11.5 | 6 | 34 | 35.5 |
| 24 | Aug 17, 95 | P | Alaska | 48 | 50 | 10.5 | 4.5 | 26 | 32.5 |
| 25 | Aug 17, 95 | P | Alaska | 60 | 57 | 12 | 6 | 36 | 34.5 |
| 25 | Aug 17, 95 | P | Alaska | 46 | 51 | 10 | 5 | 36 | 35 |
| 25 | Aug 17, 95 | P | Alaska | 60 | 54.5 | 11 | 6 | 37 | 35.5 |
| 25 | Aug 17, 95 | P | Alaska | 46 | 52.5 | 11 | 5 | 42 | 35.5 |
| 25 | Aug 17, 95 | P | Alaska | 56 | 56.5 | 11 | 6 | 28 | 32 |
| 25 | Aug 17, 95 | P | Alaska | 64 | 57 | 12 | 6.5 | 24 | 30 |
| 25 | Aug 17, 95 | P | Alaska | 48 | 53 | 10 | 5 | 30 | 32.5 |
| 25 | Aug 17, 95 | P | Alaska | 64 | 58.5 | 12 | 6 | 40 | 36.5 |
| 25 | Aug 17, 95 | P | Alaska | 44 | 51.5 | 10 | 5 | 28 | 31 |
| 25 | Aug 17, 95 | P | Alaska | 72 | 60 | 12 | 5.5 | 46 | 38 |
| | | | Sum | 18678 | 19002.5 | 3838 | 1845 | 12189 | 11826 |
| | | | Avg | 53.37 | 54.29 | 10.97 | 5.27 | 34.83 | 33.79 |
| | | | Std | 8.38 | 2.79 | 0.99 | 0.81 | 5.89 | 2.38 |

**Appendix B**

**Data Used for Determining the Weight of Salmon from its Cross-sectional Profile**

This appendix presents the experimental data used for determining the weight of salmon from its cross-sectional profile.

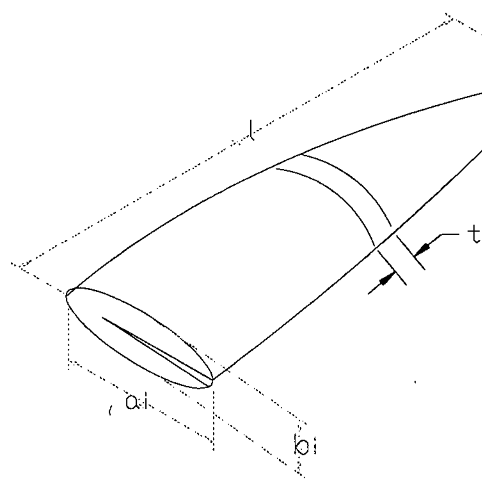


**Figure B-1** Various Dimensions for Determining the Weight of Salmon from its Cross-sectional Profile.

Fish # 1

| ai | bi | ai | bi | ai | bi |
|---|---|---|---|---|---|
| 2.9 | 1.6 | 11.9 | 4.9 | 1 | 3.9 |
| 3 | 1.7 | 12 | 5 | 0.5 | 3 |
| 3.1 | 2 | 12.1 | 5.1 | 0.1 | 1 |
| 3.2 | 2.2 | 12.2 | 5.1 | | |
| 3.4 | 2.3 | 12.2 | 5.2 | | |
| 3.6 | 2.5 | 12.3 | 5.2 | | |
| 3.9 | 2.7 | 12.4 | 5.2 | | |
| 4.4 | 2.8 | 12.4 | 5.2 | | |
| 4.7 | 2.9 | 12.4 | 5.3 | | |
| 5.1 | 3.1 | 12.4 | 5.3 | | |
| 5.5 | 3.2 | 12.3 | 5.3 | | |
| 5.7 | 3.4 | 12.2 | 5.4 | | |
| 6 | 3.5 | 12.2 | 5.4 | | |
| 6.2 | 3.6 | 12.1 | 5.4 | | |
| 6.5 | 3.7 | 12 | 5.4 | | |
| 6.9 | 3.8 | 12 | 5.4 | | |
| 7.1 | 3.8 | 11.9 | 5.4 | | |
| 7.5 | 3.8 | 11.9 | 5.3 | | |
| 7.8 | 3.8 | 11.8 | 5.3 | | |
| 8.2 | 3.8 | 11.6 | 5.2 | | |
| 8.6 | 3.8 | 11.5 | 5.1 | | |
| 9 | 3.8 | 11.4 | 5 | | |
| 9.2 | 3.9 | 11.3 | 5 | | |
| 9.6 | 3.9 | 11.2 | 5 | | |
| 9.8 | 3.9 | 1.1 | 5 | | |
| 10 | 4 | 11 | 5 | | |
| 10.2 | 4 | 10.9 | 5 | | |
| 10.3 | 4 | 10.7 | 4.9 | | |
| 10.5 | 4 | 10.5 | 4.9 | | |
| 10.7 | 4 | 8.6 | 4.9 | | |
| 10.8 | 4.2 | 7.5 | 4.8 | | |
| 10.9 | 4.3 | 6.3 | 4.8 | | |
| 11.1 | 4.5 | 5.4 | 4.8 | | |
| 11.2 | 4.5 | 5.1 | 4.7 | | |
| 11.4 | 4.6 | 4.6 | 4.7 | | |
| 11.5 | 4.6 | 4 | 4.6 | | |
| 11.6 | 4.6 | 3.4 | 4.5 | | |
| 11.7 | 4.7 | 2.7 | 4.4 | | |
| 11.8 | 4.9 | 2.1 | 4.3 | | |

Fish # 2

| ai | bi | ai | bi | ai | bi |
|---|---|---|---|---|---|
| 3 | 2.6 | 11.3 | 5 | 2.7 | 4 |
| 3.1 | 2.7 | 11.3 | 5 | 2.5 | 3.8 |
| 3.3 | 2.7 | 11.4 | 5 | 1 | 3.3 |
| 3.5 | 2.8 | 11.4 | 5 | 0.9 | 2.9 |
| 3.7 | 2.8 | 11.3 | 5 | 0.5 | 2 |
| 3.7 | 2.8 | 11.4 | 5 | | |
| 3.9 | 2.8 | 11.5 | 5 | | |
| 4.2 | 2.8 | 11.5 | 5 | | |
| 4.5 | 2.9 | 11.5 | 5 | | |
| 5 | 2.9 | 11.5 | 5 | | |
| 5.4 | 2.9 | 11.5 | 5 | | |
| 5.6 | 3 | 11.5 | 5 | | |
| 5.8 | 3 | 11.6 | 5 | | |
| 6.1 | 3.1 | 11.5 | 5 | | |
| 6.4 | 3.2 | 11.4 | 5.1 | | |
| 6.7 | 3.3 | 11.3 | 5 | | |
| 7 | 3.4 | 11.2 | 5 | | |
| 7.4 | 3.5 | 11 | 5.1 | | |
| 7.7 | 3.6 | 10.8 | 5.1 | | |
| 8 | 3.8 | 10.7 | 5.1 | | |
| 8.4 | 3.9 | 10.6 | 5.1 | | |
| 8.8 | 4 | 10.5 | 5.1 | | |
| 9.2 | 4.1 | 10.5 | 5.1 | | |
| 9.5 | 4.2 | 10.4 | 5.1 | | |
| 9.7 | 4.3 | 10.3 | 5.1 | | |
| 9.9 | 4.4 | 10.2 | 5.1 | | |
| 10.2 | 4.4 | 10 | 5.1 | | |
| 10.3 | 4.5 | 9.9 | 5.1 | | |
| 10.4 | 4.6 | 9.9 | 5.1 | | |
| 10.5 | 4.7 | 9.8 | 5.1 | | |
| 10.6 | 4.8 | 9.7 | 5.1 | | |
| 10.7 | 4.8 | 9.6 | 5.1 | | |
| 10.7 | 4.9 | 8.1 | 5.1 | | |
| 10.7 | 5 | 7 | 4.9 | | |
| 10.9 | 5 | 5.7 | 4.7 | | |
| 11 | 5 | 5 | 4.5 | | |
| 11.1 | 5 | 4.6 | 4.3 | | |
| 11.2 | 5 | 3.9 | 4 | | |
| 11.2 | 5 | 3 | 4 | | |

Fish # 3 (Frozen)

| ai | bi | ai | bi | ai | bi |
|---|---|---|---|---|---|
| 5 | 2.6 | 13.6 | 6.1 | 7.3 | 5.7 |
| 5 | 2.7 | 13.9 | 5.9 | 6.6 | 5.5 |
| 4.8 | 2.8 | 14.1 | 5.7 | 4.5 | 5.3 |
| 4.6 | 3 | 14.1 | 5.7 | 4.2 | 5.2 |
| 4.3 | 3.2 | 14.2 | 5.7 | 3.7 | 4.5 |
| 4.4 | 3.5 | 14.1 | 5.7 | 3.2 | 4.2 |
| 4.4 | 3.6 | 14.1 | 5.7 | 3 | 4 |
| 4.8 | 3.8 | 14.1 | 5.7 | | |
| 5.1 | 3.9 | 14 | 5.7 | | |
| 5.5 | 4 | 14 | 5.8 | | |
| 5.7 | 4.1 | 14 | 5.9 | | |
| 6.1 | 4.2 | 14 | 6 | | |
| 6.6 | 4.4 | 14 | 6.3 | | |
| 7 | 4.5 | 14 | 6.4 | | |
| 7.3 | 4.6 | 14 | 6.5 | | |
| 7.5 | 4.6 | 13.9 | 6.5 | | |
| 7.7 | 4.7 | 13.9 | 6.6 | | |
| 8 | 4.9 | 13.8 | 6.6 | | |
| 8.4 | 5.1 | 13.7 | 6.7 | | |
| 8.7 | 5.1 | 13.7 | 6.7 | | |
| 9 | 5.4 | 13.7 | 6.8 | | |
| 9.2 | 5.5 | 13.6 | 6.8 | | |
| 9.3 | 5.6 | 13.5 | 6.9 | | |
| 9.4 | 5.6 | 13.5 | 7 | | |
| 9.5 | 5.6 | 13.4 | 7 | | |
| 9.8 | 5.6 | 13.4 | 7 | | |
| 10 | 5.8 | 13.4 | 6.9 | | |
| 10.3 | 6 | 13.3 | 6.9 | | |
| 10.4 | 6.1 | 13 | 6.9 | | |
| 10.5 | 6.2 | 12.6 | 6.8 | | |
| 10.7 | 6.2 | 12.4 | 6.7 | | |
| 10.9 | 6.3 | 12.1 | 6.6 | | |
| 11.5 | 6.4 | 12 | 6.6 | | |
| 12 | 6.4 | 11.9 | 6.5 | | |
| 12.5 | 6.4 | 11.9 | 6.4 | | |
| 12.6 | 6.3 | 11.7 | 6.3 | | |
| 12.9 | 6.3 | 11.7 | 6.2 | | |
| 13.2 | 6.1 | 9.7 | 6.1 | | |
| 13.4 | 6 | 8.5 | 5.9 | | |

Fish # 4 (Frozen)

| ai | bi | ai | bi | ai | bi |
|---|---|---|---|---|---|
| 4 | 2.5 | 12.7 | 5.9 | 6 | 6 |
| 4.1 | 2.5 | 12.8 | 5.9 | 4.5 | 5.5 |
| 4.25 | 2.6 | 12.9 | 5.9 | 4.1 | 5.1 |
| 4.5 | 2.6 | 12.9 | 5.9 | 3.2 | 4.8 |
| 4.7 | 2.7 | 13 | 5.9 | 2 | 4.2 |
| 4.9 | 2.8 | 13.2 | 5.9 | 1.5 | 3.8 |
| 5 | 2.8 | 13.4 | 5.9 | 4.5 | 0.5 |
| 5.2 | 2.8 | 13.5 | 5.9 | | |
| 5.6 | 2.8 | 13.6 | 5.9 | | |
| 6.2 | 2.8 | 13.7 | 5.9 | | |
| 6.5 | 2.8 | 13.8 | 5.9 | | |
| 7 | 2.9 | 13.9 | 5.9 | | |
| 7.2 | 2.9 | 13.9 | 5.9 | | |
| 7.5 | 2.9 | 13.9 | 5.9 | | |
| 7.85 | 3 | 13.9 | 6 | | |
| 8 | 3.2 | 13.9 | 6 | | |
| 8 | 3.3 | 14 | 6.1 | | |
| 8.2 | 3.3 | 14 | 6.1 | | |
| 8.45 | 3.5 | 13.9 | 6.2 | | |
| 8.65 | 3.7 | 13.9 | 6.2 | | |
| 8.9 | 3.8 | 13.8 | 6.4 | | |
| 9 | 3.9 | 13.9 | 6.5 | | |
| 9.3 | 4 | 13.8 | 6.5 | | |
| 9.5 | 4.2 | 13.7 | 6.6 | | |
| 9.8 | 4.2 | 13.7 | 6.6 | | |
| 10.5 | 4.4 | 13.5 | 6.6 | | |
| 10.2 | 4.5 | 13.4 | 6.5 | | |
| 10.5 | 4.6 | 13.2 | 6.5 | | |
| 10.8 | 4.7 | 13 | 6.4 | | |
| 10.9 | 4.8 | 12.8 | 6.3 | | |
| 11.2 | 5 | 12.6 | 6.2 | | |
| 11.5 | 5.1 | 12.4 | 6.2 | | |
| 11.7 | 5.2 | 12.1 | 6.2 | | |
| 11.9 | 5.3 | 11.8 | 6.3 | | |
| 12.1 | 5.5 | 11.4 | 6.3 | | |
| 12.2 | 5.6 | 11.3 | 6.3 | | |
| 12.4 | 5.6 | 11 | 6.1 | | |
| 12.5 | 5.7 | 8 | 6.1 | | |
| 12.6 | 5.8 | 7.5 | 6 | | |

## Appendix C

## Experimental Setup Details

This appendix presents the stepper motor drive circuit and model details of various components of the experimental setup.

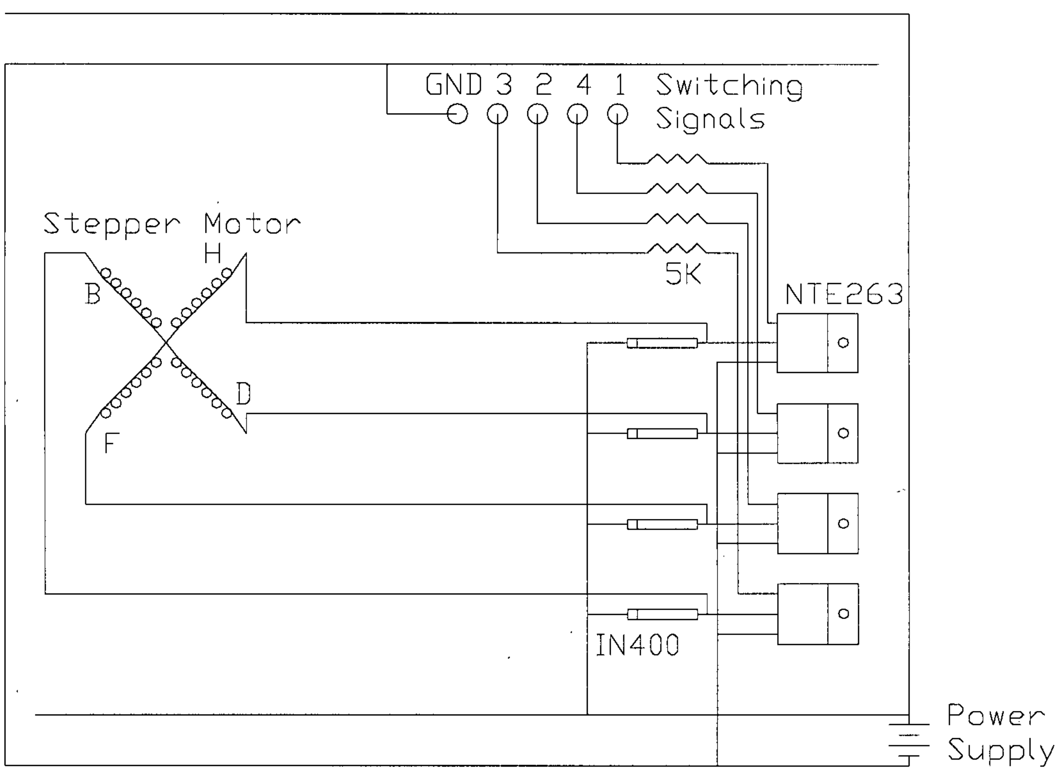


**Figure C-1** Stepper Motor Drive Circuit.

**Model Details of Components:**

**i) Stepper Motor**

Quantity = 3 nos.

Model: SIGMA 20-4247TD-24245

Unipolar Stepping Motor, 12V, 1.7A, 1.8deg./step, 4.2Ω coil resistance/ph., 400 oz.in. running torque at 50 PPS , approx. 450-500 oz.-in. stall torque.

Body 4.25″ dia. × 4.7″ long.

Shaft 0.375″ dia × 1.3″ long.

Face Mount, 3 tapped holes on 3″ bolt circle.

**ii) Solenoid**

Quantity = 1 nos.
Model: Guardian #18AC 120

**iii) Ball Screw and Nut Assembly**

Quantity = 2 nos.

Model: Ball Screw and Actuators, RB30-2

5/8″ nominal dia., 0.2″ lead

Torque reqd. to raise 1 lb = 0.035 lb.in.

**iv) Linear Bearings**

Quantity = 2 nos.

Model: Thomson, SPB-16

1.0″ nominal bearing dia. (bore)