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*Performance Testing of an Onion Peeling Machine
Using Response Surface Methodology*

presented by

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has been accepted towards fulfillment
of the requirements for

M.S. degree in Aggr. Engr.

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**PERFORMANCE TESTING OF AN ONION
PEELING MACHINE USING RESPONSE SURFACE
METHODOLOGY**

By

Ling Wang

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

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ABSTRACT

PERFORMANCE TESTING OF AN ONION PEELING MACHINE USING RESPONSE SURFACE METHODOLOGY

By

Ling Wang

An onion peeling machine was characterized by peeling efficiency, peeling capacity and machine peeling loss. Onion shape, onion size, air pressure and chain speed (each in three levels) were investigated as major factors affecting the machine's performance. Three types of Response Surface Design (Hoke D_6 , Bos-Behnken and factorial) were conducted to test the machine. The optimization of the process was performed to result in maximum peeling efficiency and minimum peeling loss. The computer generated response surfaces, the canonical analysis and the superimposed contour plots revealed that the speed of 84 onions/min combined with the air pressure of 517 kpa on round shape and medium size (83 mm) pungent Machine onions should yield an optimal operating condition with a peeling efficiency of 80% while keeping machine peeling loss as low as 25%. At these levels, 576 kg/h peeling capacity is obtainable.

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DEDICATION

I dedicate this thesis to my parents, Xi Wang and You Xian Dong. They gave me the love and the strength. They indicated the direction for me and urged me to realize the ideal. My appreciation to them is beyond words. It is right that the results of their tremendous support and persistent encouragement, should bring success in my life.

I also dedicate this thesis to Young Ming Sun, my undergraduate program teacher. He was the first person who guided me into the domain of mechanical engineering with his extensive knowledge and noble-minded morality in teaching and research.

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LIST OF SYMBOLS

<i>Symbol</i>	<i>Definition</i>
β_i	= <i>constant coefficient</i>
C_p	= <i>peeling capacity</i>
d	= <i>onion equatorial diameter</i>
d_i	= <i>space between the low and high level of ξ_i</i>
DF	= <i>degree of freedom</i>
E	= <i>peeling efficiency</i>
ε	= <i>random error</i>
η	= <i>some response</i>
F -value	= <i>the ratio of mean square</i>
h	= <i>onion longitudinal height</i>
λ	= <i>the chacteristic root of the B-matrix</i>
M_{Loss}	= <i>machine peeling loss</i>
MS	= <i>mean square</i>
P -value	= <i>significance level</i>
R^2	= <i>the coefficient of multiple determination</i>
R_a^2	= <i>the adjusted R^2</i>
SS	= <i>sum of square</i>
W_i	= <i>initial sample weight</i>
W_m	= <i>sample weight after machine peeling</i>
W_f	= <i>final sample weight</i>

<i>Symbol</i>	<i>Definition</i>
$W_{(1-4)}$	= <i>the coefficients of canonical form</i>
ξ_i	= <i>actual value in original units of independent variable</i>
$\bar{\xi}_i$	= <i>mean of high and low levels of ξ_i</i>
x_i	= <i>coded variables</i>
x_1	= <i>onion shape</i>
x_2	= <i>onion size</i>
x_3	= <i>air pressure</i>
x_4	= <i>chain speed</i>
$\hat{Y}_E$	= <i>estimated peeling efficiency</i>
$\hat{Y}_{ml}$	= <i>estimated machine peeling loss</i>

CHAPTER I

INTRODUCTION AND PROBLEM DESCRIPTION

1.1 Background

1.1.1 Economic Significance

Onions have been a popular food for many centuries. Today they are valued for their flavor, aroma, and taste, being prepared domestically or forming raw materials for a variety of food processes (dehydration, freezing, canning and pickling). They are probably the most universally used vegetable in most countries.

Bulbs of the common onion (*Allium Cepa*) and their products are an important trade item and appear in most markets of the world throughout the years (Table 1 and Figure 1). According to the *1990 yearbook of the Food and Agriculture Organization of the United Nations*, total production of dry onions in that year was about 28 million tons (Table 2). Comparing the production of 1974, the world production of dry onions increased almost 70% in 1990. The total value of dry onion world traded in 1989 was \$1096 million, an increase of 54% over 1982. The main production was in Asia (49%), followed by Europe, including the U.S.S.R. (25%), the Americas (18%), and Africa (7%). It is estimated that the value of the world

Table 1
Onion World Trade: Production and Value, 1982 - 1989

	Import		Export	
Year	Production (MT)	Value (1000\$)	Production (MT)	Value (1000\$)
1982	1,726,468	416,840	1722,045	336,016
1983	1,741,058	378,079	1,749,620	313,750
1984	1,954,169	541,934	1,931,715	441,460
1985	1,931,206	393,265	1,895,821	289,981
1986	1,923,078	435,805	1,951,731	345,034
1987	2,075,274	628,385	2,124,896	489,741
1988	2,157,050	603,720	2,192,990	531,318
1989	2,103,287	577,836	2,006,702	518,026

production of bulb onions alone approaches \$7 billion annually. Since bulb onions are an easily transportable commodity and can be stored for a period, approximately \$500 to \$600 millions worth (at 1989 prices) are traded internationally each year. The crop is a major export earner for some economies. The most important onion producers in 1990, with their production, harvested area and yield are shown in Table 3. The major exporter and importer countries in 1989, with their quantities and value are shown in Table 4. In addition, the common onion is also an important salad crop when eaten green. Because of onion's economic importance, great efforts have been made in the development of its cultural and processing techniques. As a result, their cultivated regions, yields and productions have increased over the years.

Table 2
The World Dry Onion: Area Harvested, Yield and Production, 1988 - 1990 *

	Area Harvested (1000 ha)				Yield (Kg/ha)				Production (1000 MT)			
	1979-81	1988	1989	1990	1979-81	1988	1989	1990	1979-81	1988	1989	1990
World	1604	1823	1858	1977	13267	14837	14637	14120	21279	27042	27195	27918
Africa	118	161	165	170	12860	12152	10691	11256	1517	1959	1764	1916
N C America	62	76	75	78	28987	31120	32335	34437	1811	2350	2427	2697
S America	128	144	149	153	13975	15250	14991	15261	1790	2203	2241	2342
Asia	884	1005	1037	1053	11341	12878	12791	13018	10024	12945	13263	13709
Europe	233	246	239	328	17483	19350	20089	14795	4073	4754	4804	4848
Oceania	4	5	5	5	30054	35017	36216	37916	121	191	197	206
USSR	174	185	187	189	11143	14270	13369	11640	1943	2640	2500	2200
Dev.Ped All	502	536	532	626	18383	21154	21327	18159	9221	11329	11350	11374

* All data presented in the tables and figures in this chapter were cited from the *Yearbook of the Food and Agriculture Organization of the United Nations*.

Table 3
The World Ten Leading Dry Bulb Onion Producers in 1990

Producer Countries	Total Production 1000 MT	Area Harvested 1000 ha	Yield 1000 kg/ha
Chain	3930	248	15.9
India	3350	320	10.5
U.S.	2454	58	42.5
USSR	2200	189	11.6
Turkey	1550	79	19.6
Japan	1280	29	44.1
Spain	1063	30	36.0
Brazil	984	74	11.6
Iran	700	30	23.3
Poland	550	30	18.4

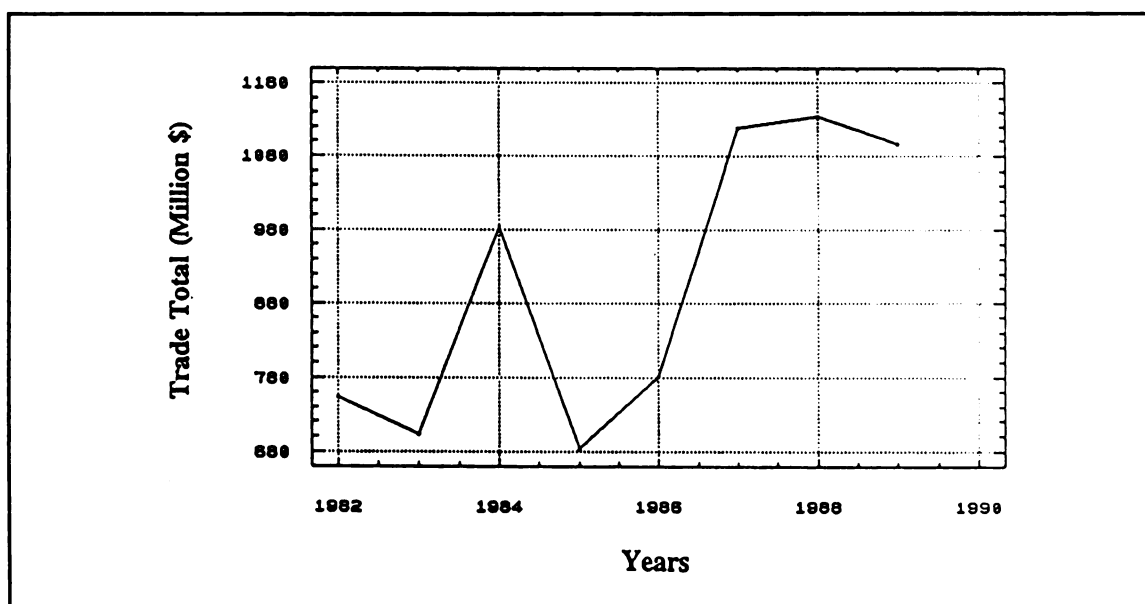


Figure 1 Onion world trade total, 1982-1989

Table 4
The Ten World Leading Exporter and Importer Countries
for Dry Bulb Onions in 1989

Exporter Country	Quantity 1000 MT	Value 10⁶\$
Netherlands	415	100
Spain	233	58
India	230	35
Mexico	150	75
Turkey	150	17
U.S.	110	37
Poland	60	20
Italy	55.5	24
Australia	50	20
Pakistan	27	3

Import Country	Quantity 1000 MT	Value 10⁶\$
FR Germany	335	74
UK	240	57
U.S.	163	69
France	135	35
Malaysia	117	32
Canada	110	13
United Arab Emirates	71	31
Bel-Lux	77	18
Singapore	64	20
Kuwait	40	8

Onion cultivation in the U.S. was 1,508 million kg (42,489 ha.) in 1973 and 2,433 million kg (53,647 ha.) in 1989 (Table 5). Over this period the production increased about 65% and the growing area increased only about 29%. The U.S. onion yield, kg/ha, is one of two highest in the world. The value of the crop increased about 150% from \$207 million in 1973 to \$502 million in 1989. Making it the third most valuable of commercial vegetables, behind tomatoes (\$1,824 million) and lettuce (\$950 million).

Two crops of onions are grown each year in the U.S., as shown in Table 6. A spring crop is grown in Arizona, California and Texas, and the total production was 375 million kg, valued at \$91 million in 1989. The summer crop is much larger, in excess of 2,058 million kg in 1989, valued at \$462 million, comprising both non-storage produce (232 million kg, grown primarily in New Mexico, Texas and Washington) and storage produce (1,312 million kg, predominantly from Colorado, Idaho, Michigan, Minnesota, New York, Ohio, Oregon, Utah, Washington and Wisconsin). In addition, 514 million kg were grown in California and were used mainly for processing. The summer crop occupied about 85% of annual total production in 1989. From 1973 to 1988 the onion imports of the U.S. increased rapidly and exports fluctuated around 100 million kg, as shown in Figure 2. In 1982, U.S. fresh onion exports dropped from its peak of 194 million kg in 1981 to 69 million kg. Since then, the situation has improved somewhat. However, it looks fairly weak if we compare it with the trend toward fresh onion imports, even though, in the last 15 years, the yield has increased from 35,523 kg/ha (1973) to 42,530 kg/ha (1989). However, due to the low cost of production in foreign countries, U.S. onion producers

Table 5
Onions Area, Production and Value in the United States, 1973-1989

Year	Area (ha)	Production (million kg)	Value (10 ³ \$)
1973	42,489	1,508	207,226
1974	44,408	1,684	147,182
1975	41,717	1,596	266,230
1976	44,323	1,793	217,202
1977	43,930	1,757	204,314
1978	49,341	1,838	251,495
1979	50,146	1,961	237,432
1980	45,796	1,676	347,054
1981	45,339	1,786	475,470
1982	50,960	2,127	307,501
1983	49,794	1,969	431,906
1984	52,348	2,218	422,538
1985	49,681	2,289	347,247
1986	46,678	2,200	427,669
1987	50,069	2,330	511,090
1988	53,481	2,452	426,293
1989	53,647	2,433	502,124

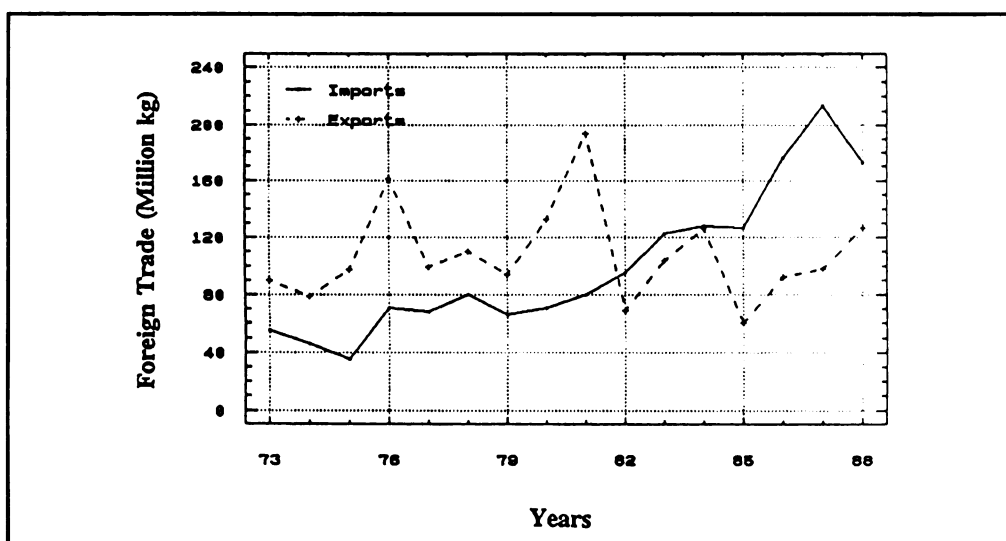


Figure 2 Onion fresh market: Foreign trade, The U. S., 1973-1988

Table 6
Onions' Area and Production by State in The US, 1985-1989

Season and State	Area (ha)						Production (million kg)					
	1985	1986	1987	1988	1989		1985	1986	1987	1988	1989	
Spring:												
AZ	486	486	526	486	405		29	34	30	23	22	
CA	3,157	3,157	3,319	3,439	3,116		178	147	163	168	157	
TX	6,880	4,856	5,059	5,666	6,071		164	183	140	164	164	
Total	10,522	8,500	8,903	9,591	11,494		371	363	332	355	375	
Summer-Non Storage: NM	1,821	1,902	2,185	2,590	3,035		74	92	107	140	152	
TX	1,659	2,145	1,902	1,659	1,619		48	81	41	44	53	
WA	526	526	567	647	607		20	22	27	33	27	
Non storage Total	4,007	4,573	4,654	4,897	5,261		142	192	175	216	232	
Storage:												
CO	5,099	4,371	5,059	5,463	5,585		272	233	238	281	280	
ID	2,752	2,833	3,116	3,076	2,995		190	189	234	205	203	
MI	3,157	2,307	3,075	3,238	3,197		129	84	97	102	112	
MN	271	263	263	243	271		10	11	10	6	8	
NY	5,342	5,180	4,695	4,735	4,533		201	176	159	149	148	
OH	198	198	190	223	198		11	9	7	8	10	
OR(Malheur)	3,885	3,440	3,723	4,087	3,966		268	229	280	272	269	
OR (Other)	1,416	1,295	1,457	1,457	1,417		76	73	77	66	72	
UT	648	567	688	729	769		37	24	42	35	43	
WA	1,740	178	2,024	2,266	2,509		90	94	117	128	142	
WI	526	486	486	526	526		22	19	17	18	25	
Storage Total	25,034	22,720	24,776	26,042	25,966		1,306	1,141	1,278	1,270	1,312	
CA	10,118	10,886	11,736	11,655	10,927		470	506	501	534	514	
Total Summer	39,159	38,179	41,166	42,595	42,153		1,918	1,837	1,954	2,019	2,058	
US	49,681	46,678	50,069	52,186	53,647		2,289	2,199	2,286	2,374	2,433	

have met a severe challenge.

According to Jones and Mann (1963), the production of dehydrated onions in the U.S. increased from 900 tons to over 9,000 tons between 1947 and 1961. Given the more recent improvements in processing technology, the expansion of fast food outlets and the increasing stringency of quality and microbiological safety standards, the catering industry generally and the convenience food sector in particular, demand for these products as well as oleoresin and essential oils has undoubtedly increased greatly since 1961. Detailed information about the extent and value of trade in these products is difficult to ascertain, however.

1.1.2 Onion Products

The main commercial onion products are: dehydrated onion pieces, onion powder, onion flavoring (including onion oil and onion juice), onion salt, pickled onions, and canned onions (Fenwick and Hanley, 1989).

To produce dehydrated onions, onion bulbs first need to be cleaned and peeled, then cut into slices. The onion slices are automatically spread on a continuous stainless-steel perforated belt, and hot air is blown through the bed. The residual moisture content of the product should be 4% to 5% to allow for good storage and acceptable flavor stability. Dehydrated onion pieces can be put into the market not only as final outcome, but also can be converted into powder, granules, flakes, kibbled or sliced or used to prepare such products as onion salt, french fried onion rings or toasted onions. The convenience and quality of today's commercial dehydrated onion products

have earned them a large market. Tomato catsup contains about 1% fresh onion equivalent by weight, and chili sauce contains up to 4%. The U.S. catsup and chili sauce industries use approximately 454,000 kg of dehydrated onion annually; more than 227,000 kg are used annually in comminuted meat products. Sauces, soups, mayonnaise, salad dressing, pickles and pet food contain dehydrated onions as a component (Somogyi and Luk, 1988).

Onion powder may be obtained by grinding dehydrated onion pieces, but a stronger flavored product may be obtained by spray drying. In this product, the onions are peeled and washed free of debris, rinsed and blended to a puree. For best results particle size should be below 0.3 mm. Onion powder is used when onion appearance and texture are not requirements of product formulation (e.g., in dehydrated soups, relishes, and sauces).

Onion oil is the most highly processed onion products. The product is used for its solubility, lack of color and strong aroma. It can be obtained by the distillation of minced onion which has been allowed to stand for some hours prior to distillation. The oil itself, a brown-amber liquid obtained in 0.002 to 0.03% yield, comprises a complex mixture of (mainly) sulfur containing volatile. The product possesses (on a weight basis) 800 to 1000 times the strength of odor of fresh onion, but its commercial value may be many thousands of times that of the onion. The product is used for its solubility, lack of color, and strong aroma. Onion oil has been reported to be used in nonalcoholic beverages, ice cream and ices, confectionery, baked goods, condiments, meats and pickles.

Sterile onion juice is obtained by the repeated expression of onion tissue, flash heating the resulting liquor to 140°C to 160°C and immediate

cooling to 40°C. The juice is carefully evaporated (18°C to 40°C), usually to 72% to 75% dry matter, which is necessary for preservation without the need for chemical additives. The concentrated juice is pale brown in color, possesses a strong fresh onion odor but lacks the undesirable bitterness which characterizes the untreated juice. Further evaporation to 82 to 85% solids leads to a darkening of the product and to the introduction of desirable cooked, toasted, sensory qualities. This extract is often mixed with propylene glycol, lecithin and glucose to yield onion oleoresin having a flavor intensity ten times that of onion powder (and a hundred times that of the original bulb).

Onion salt is a mixture of onion powder and salt together with an anticaking agent. Under U.S. specification it comprises the dehydrated powder (18 to 29%), calcium stearate (1 to 2%), and sodium chloride.

Fresh onions may be preserved in vinegar as pickled onions. Generally, silver-skin or button onions are used, as they give a more desirable product. After trimming and peeling the onions are fermented in a 10% salt solution, which has the effect of producing a translucent product with the desired firmness of texture.

Canned onions are sold in volume in U.S.. The onions, which are generally white skinned small onions (less than 38 mm in diameter), are first peeled. After blanching (4 to 5 min) in acidified water at about 82°C, the onions are canned, brined, and acidified. This latter process is necessary since heat sterilization would destroy the quality of the product. Packaged, cut onions have been stored in cartons at -18°C for 12 months without any observable change in appearance, flavor or aroma (Luh and Kean, 1988).

1.1.3 Onion Peeling Methods

From the above survey we can see that in onion processing, after grading and curing, the first operation is peeling. There are several peeling method applied in onion products manufacturing. The main methods used in the modern onion processing industry are machine peeling, lye treatment and flame peeling.

Flame peeling is usually done with natural gas at high temperatures (about 2,000°F). The roots and outer shell are burnt off in an oven. The loose, charred particles are drawn off with high-velocity air, and then the onions are washed and brushed under high-pressure water sprays, to cool them and remove the charred skins and dirt. After flaming or preliminary washing, the bulbs are inspected for defects, and the tops and roots are trimmed off by hand or by one of several types of mechanical de-rooters. The onions are then given another washing, inspected, and taken to a rotary slicer where they are cut into slices for further processing. Due to the problems, such as scorching or the agglomeration, this method is little used today in the dehydration process (Fenwick, 1990).

Lye peeling actually is a chemical reaction applied to onion processing (Hanson, 1975). In this process, the step of cutting or slicing of the dried leaf and root structure from the onion bulb is eliminated. The onions are fed into a continuous washer mechanism which agitates the onion bulbs while at the same time spraying them with water to remove dirt or other foreign materials clinging to the onion bulbs. Then the onions are placed in a caustic bath for loosening and removing the outer protective skin layer.

The key to this processing is to control the concentration of the conventional caustic solution, the temperature of the solution, and the time of immersion in the solution properly for different types of onions. From the caustic bath, the onions are transferred into a washing apparatus in which the loosened protective skin layers, root structures and dried leaf structures are all removed. The onions are then conveyed by an elevator to a stone separator tank filled with water. In the tank any stones or non-floating debris sink to the bottom of the tank while the onions float and are carried out at one end of the tank by paddles. The mechanism deposits the onions upon a continuously moving inspection table where the onions are again inspected and any floating debris, such as cinders or particles of wood, are manually removed from the group of onions. From the inspection table the onions are divided and finally fed into a number of feeding conveyors which lead to a separate trimming machine.

Because the caustic solution penetrates between the layers and into the inner flesh of the onion, even though the caustic solution is subsequently neutralized, this process has already permanently harmed the texture of the onion. Thus when such onions are packaged, they have a soft or mushy texture, and the layers of inner flesh or meat of the onion are readily separated from each other, so that each onion is disintegrated and fails to retain its inherent form and shape.

Compared to the above two types of onion peeling methods, machine peeling possesses some distinctive features. In machine peeling, the tip and the root of the onion are cut physically and pressurized air or water are used to score off the peel. In this processing, there is no chemical or physical

damage to onion products and the onions keep their natural form and shape. With the development of food processing techniques, the quality of machine peeling is much higher than flame peeling and lye peeling. This is extremely important for certain onion products, such as pickled onions, packaged onions and all kinds of canning foods which contained fresh onion as an ingredient. In addition, processing onions in a timely manner and keeping them as fresh as possible, are significant for fast food service market. As a flexible processing system, the machine peeling method is suitable not only for onion growers to pre-process before they send the onions to professional food manufacturers, but also for food industrial plants for vast processing. Actually, machine peeling plays an important role even in the flame peeling and lye peeling processing system. Furthermore, in flame peeling and lye peeling the onion's outer layers and its roots are burnt and damaged completely, while in machine peeling processing all parts which are cut off or peeled by the machine can be salvaged for other uses. Therefore, the waste in onion machine peeling processing is decreased to its lowest level. Based on the literature, in past two decades, it is estimated that about 98% of onion processing patents ratified in the world were machine peeling patents.

1.2 The Origination of a Problem

In 1984, D.G.M. Co., Inc., a prominent Michigan onion producer, and the food science department at Michigan State University investigated the users of fresh vegetables in several states. According to their report (D.G.M., 1984), the volume of fresh onions used by different local food services varied from 22.7 to 681 kg per week. However, nowhere was

anyone using modern peeling equipment. Their research also showed that many institutional commissaries would prefer a fresh peeled onion product if shelf life, product quality, and supply specifications could be met. Many expressed an interest in buying peeled onions. The Campbell Soup Company, a large fresh vegetable processor, for instance, in order to insure the quality and flavor of their products, reversed themselves from ordering dehydrated onions from California at a considerable saving to go back to fresh onions. The investigator found that the peeled onion product serves as a remarkable method of discovering markets for other vegetable and food products. Several national fast food businesses had contacted with D.G.M.. They were looking for new methods of processing and packaging their fresh products to reduce costs and insure freshness. One of them, Campbell Soup Co., Inc., contracted with D.G.M. Co., Inc.. Because of this situation, and considering the potential demands of a number of food industries in Michigan and its neighboring states, such as Wendy's, Columbus, Ohio; McDonald's, Illinois; Domino's, Ann Arbor, Michigan; Little Ceasars, Detroit, Michigan; and Big Boy, Detroit, Michigan, D.G.M. Co., Inc. determined to establish an onion processing center to supply a peeled fresh onion product to the market.

Two types of onion peeling machines had been used by the D.G.M. Co. to process fresh onions before 1988 (Srivastava, 1989). One of them was the Martin machine developed in California, which is suitable for large size Western onions. But it does not work well with smaller Michigan onions. The other machine is made in Japan. It does not trim onions and requires a large amount of hand labor to finish peeling and trimming. One of the problems experienced with this machine is unavailability

of replacement parts. Both of the machines require a large amount of compressed air which represents a substantial capital investment and operating cost.

Thus, there was a need for a farm level onion peeling machine suitable for smaller Michigan onions. The Michigan Department of Commerce awarded D.G.M. Company a grant to develop an onion peeling machine in order to exploit the market as mentioned above. The D.G.M. Co. subcontracted with the Department of Agricultural Engineering at Michigan State University to develop such a machine. The system was originally designed to peel and trim onions at a rate of one onion per second. For medium Michigan onions, this amounts to a production rate of about 545 kg/hr.

In 1988, the first prototype was installed for testing at D.G.M. Co., Inc., in Stockbridge, Michigan. After one year of pilot production use and modification, by 1990, the second prototype was finished and put into operation. In 1991, the machine processed about 317,800 kg of onions for Campbell Soup Company.

1.3 Objectives

The purpose of the research reported here was to evaluate the performances of the second prototype onion machine peeling system built by the Department of Agricultural Engineering at Michigan State University. The specific objectives were:

1) To define and measure machine performance parameters as affected by the machine operating variables and the onion properties.

2) To determine the optimum operating conditions for the machine peeling system using Response Surface Methodology.

3) To make recommendations for design improvements in the machine.

CHAPTER II

REVIEW OF THEORY AND LITERATURE

2.1 Introduction

Performance Evaluation of the MSU Onion Peeling Machine, is a multi-disciplinary project. The background which needs to be reviewed is in three different fields: (1) the products (the onion and issues related to onion processing and utilization), (2) the equipment (the peeling machine and issues related to mechanical systems), and (3) the research method (Response Surface Methodology and other issues related to statistics). The basic information on the onion and its products have been presented in Chapter I. The background of peeling machines and statistical methods are presented in this chapter.

Response Surface Methodology (RSM) is a statistical tool used to analyze and optimize the operating condition of the machine system. In order to justify the use of RSM some considerations and examples of its application are presented.

The target of the research is the evaluation of the performance of a machine system which was newly developed to peel onions for the food processing industry. The use of mathematics as an aid to process

understanding does not replace experience and knowledge, though it surely acts as a significant added dimension to the qualitative approach (Harper and Wanninger, 1969). While a review of the onion peeling machine is necessary. However, there has been no published material was found which relates to the evaluation or the testing of an onion peeling machine. In order to classify this type of machine, and characterize its specific features and functions, and, in turn, locate the new machine in a proper position for an objective appraisal, a review of the literature regarding the onion peeling machine is presented here to approach a qualitative analysis. Because of the difficulties mentioned above, this review is based mainly upon the information collected from U. S. Patents.

2.2 Review of Response Surface Methodology (RSM)

2.2.1 Selecting A Quantitative Analysis Method

The first step in evaluating the performance of an onion machine peeling system is to build a mathematical model, that is, to use a set of performance or objective functions to describe the relationships of all independent variables and their responses. We want to simulate real circumstances approximately with a set of mathematical equations. In general, there are two kinds of models, the theoretical model and the empirical model. The theoretical model satisfies physical phenomena, about which we know their physical mechanisms. Usually, it is expressed by a set of differential equations or integral equations. However, when the necessary physical knowledge of the system is absent or incomplete and consequently

no theoretical model is available, an interpolation function, such as a polynomial, could be used to provide a local empirical model in which nothing could be assumed except that the response surface was locally smooth. In some applications, polynomials can be used to approximate quite complex behavior, and they are frequently applied in the case of the examination of preliminary data to give a first insight into the form of the model. The newly-developed onion peeling machine system belongs to this type of situation. In this system, there are four independent variables and a multiple-response. Because of the many variables and corresponding interactions, there is no suitable theoretical equation which can be used to describe the system. Therefore, a statistical technique which takes this into account should be used to build the empirical model for the onion machine peeling system. One of the best statistical techniques for building an empirical model for the machine peeling system is the Response Surface Methodology, which minimizes costs by reducing the number of experimental formulations and seeks optimum solutions easily by using a computer graphical approach (Floros, 1988).

2.2.2 The Basic Assumptions and Concepts of RSM

The response surface problem usually centers on an interest in some response η which is a function of k independent variables $\xi_1, \xi_2, \dots, \xi_k$, that is

$$\eta = f(\xi_1, \xi_2, \dots, \xi_k) \quad (2.1)$$

The actual form f in Eq. 2.1 is often unknown, and perhaps extremely

complicated, particularly in food engineering. But RSM assumes that it can be approximated by a polynomial function of lower order. For example, in the case of two independent variables ($k = 2$), one might assume a model of the type

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{12} x_1 x_2 + \varepsilon$$

where $\beta_0, \beta_1, \beta_2, \beta_{11}, \dots$ are constant coefficients, x 's are the coded or design variables, and the relationship between natural variable (ξ 's) and the coded (x 's) are simply linear; y is the measured response, and ε is a random error. The variables $x_1, x_2, \dots, x_k$ are quantitative and are measured on some continuous scale.

It is further assumed that the ξ 's can be controlled by the experimenter with negligible error. For example, in a food processing system where the engineer is interested in obtaining an optimal efficiency, η , of a machine processing system. The efficiency could be dependant upon air pressure (ξ_1), feeding rate (ξ_2), material properties (ξ_3), and so on. The ξ 's can be controlled by the experimenter by developing the machine system, or by adjusting the operating system with negligible error.

The success of the RSM is based on the approximation of f by a lower order polynomial in some region of the independent variables. For example, if the approximating function is linear in the variables, then we write, in terms of the design variables,

$$\eta = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_k x_k \quad (2.2)$$

and the second-order polynomial is

$$\eta = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_k x_k + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \dots + \beta_{k-1,k} x_{k-1} x_k + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \dots + \beta_{kk} x_k^2 \quad (2.3)$$

The coefficients $\beta_0, \beta_1, \beta_2, \dots$ are parameters to be estimated from the data collected in the experiment. For $k = 2$ experimental variables, these general polynomials reduce to

$$\eta = \beta_0 + \beta_1 x_1 + \beta_2 x_2 \quad (2.4)$$

and

$$\eta = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{12} x_1 x_2 + \beta_{11} x_1^2 + \beta_{22} x_2^2 \quad (2.5)$$

Strictly speaking, Equations 2.2, 2.3, 2.4 and 2.5 should not be written as equalities. But it is usually assumed that the approximation is so close that any lack of fit will remain undetected with some experimentation, so that for practical purposes it is reasonable to write them as equalities and this is common practice.

The assumptions which are fundamentally used in the RSM are summarized as follows:

(1) A mathematical model $\eta = f(x_1, x_2, \dots, x_k)$ exists and is either very complicated or unknown. The variables involved in this model are quantitative and continuous.

(2) The function f can be approximated in the region of interest by a low-order polynomial such as Equation 2.2 or 2.3.

(3) The independent variables $x_1, x_2, \dots, x_k$ are controlled by the

experimenter and measured with negligible error.

2.2.3 The Applications of The RSM in The Mechanical and Food Processing System

In the past four decades, Response Surface Methodology, as an experimental strategy, has been employed with considerable success in a wide variety of situations.

RSM was initially developed and described by Box and Wilson in 1950. In their paper, a scientific approach to determining optimum conditions was described which combined special experimental designs with the Taylor First and Second Order Equations in a sequential testing procedure called "Path of Steepest Ascent." The fundamentals of RSM and its underlying philosophy are discussed in many papers and a number of textbooks. The most comprehensive discussion is that given in the book, *Empirical Model Building and Response Surface*, by G. E. P. Box and N. R. Draper in 1987.

From the early 1950's to the mid-1960s, a number of statisticians and scientists published articles which described their great interests in developing and consummating RSM as a powerful optimal method. During this period, they confined their efforts mainly to the application of composite design and the method of steepest ascent in the fields of chemistry and chemical engineering, biochemical and pharmaceutical sciences, as well as in agricultural research (Hill, 1966).

In 1957, Box introduced the idea of evolutionary operation (EVOP),

which assumes normal operation of the industrial process within which systematic changes would be made giving experimental information. And, Box and Hunter introduced the concept of rotatability (Box and Hunter, 1957). In 1959, Box and Draper discussed the various reasons for choosing a design to investigate a response surface (Box and Draper, 1959) and Box and Lucas discussed the criterion used for selection of a design which minimized the variance of the parameter estimates (Box and Lucas, 1959).

During the same period, there were three other major lines of statistical research on RSM developed by: (1) Robbins and Monro concerning Stochastic Approximation (1951); (2) Rao concerning Growth Curves (1958); and (3) Kiefer concerning Optimal Design. In addition to these major developments there were extensions in the design of experiments, the form of response curves, the fitting of response curves and in the general field of data checking (Mead and Pike, 1975).

The more recent work on RSM has been the emphasis on non-linear models (Box, 1971) and the increasing use of the computer (Cady, 1970), which has been an important factor in the choice of fitting methods as well as in the computer graphics approach (Richard, 1979), (Floros, 1988).

According to Hill and Hunter (1966), RSM has been successfully applied in mechanical and food engineering. In these two fields, RSM is mainly used in machine processing systems to find a suitable approximating function for optimizing the operating condition, and in product development to determine what values of the independent variables are optimum as far as the response is concerned. The optimization phase of the problem often involves finding the values of $x_1, x_2, \dots, x_k$, which maximize the response.

A discussion of some successful applications follows.

In mechanical systems, Whidden applied RSM to conduct two experiments in metals processing. One is to optimize the green tensile strength in the sand casting process, in which the dry mulling time was tested as an independent variable. Another is in the development of an alloy to determine the aging time and temperature which maximized the tensile yield strength and the elongation of aluminum (Whidden, 1956).

Ross applied RSM in research of Aeroprojects, in which a new and unique process, ultrasonic welding, was developed for finding the relationship between the independent results (strength of weld) and the controllable factors (power, clamping force, etc.) (Ross, 1961).

Underwood successfully applied RSM in designing extrusion screws. In his experiment, the length of the metering section, the channel depth in the metering section, the channel depth in the feed section and the screw speed were considered as independent variables. Rate of extrusion, melt temperature, net power required, smoothness of operation and thoroughness of mixing were dependent variables (Underwood, 1962).

Wu successfully applied RSM to optimize the metal processing in a machine tool system, and a series of results were obtained in different subjects. Wu indicated in his research report (Wu, 1964a and 1964b) that with RSM, the number of tests to develop tool-life predicting equations can be substantially reduced. The reliability of such an equation can also be estimated. Three independent variables, speed, feed and depth of cut, were

investigated in the project. In his other research project (Wu, 1964c) he indicated that empirical general cutting-tool temperature-predicting equations, in terms of speed, feed and depth of cut, were developed by RSM. Later, he added two new independent variables, the side-cutting-edge angle and nose radius, into the model, and further developed the cutting-tool temperature model to a five-variable predicting equation (Wu, 1964d).

In 1979, Bemesderfer, a senior engineer and statistician at General Electric presented an eight-point program for the approval of complex new processes prior to their introduction to production. Data collection was based on response surface experiments. He indicated that the use of the procedures has resulted in greater confidence in new processes and in demonstrably better processes, both in the development laboratory and in the factory. His research included roll burnishing, electrochemical machining, electrical discharge machining, laser machining, electroplating, vapor deposition coatings, thermal spray coatings, inertia welding, brazing, and abrasive flow machining. Particularly, he indicated that there is no reason the procedures cannot be applied to any manufacturing process, regardless of its nature, e.g., mechanical machining, casting, and heat treatment (Bemesderfer, 1979).

Geier and Hood applied RSM to build an empirical model for metal processing. In their study, mean cutting force as a function of depth of cut and kerf depth, as well as mechanical specific energy as a function of depth of cut and kerf depth, were developed to describe the influence of preweakening a rock on the cutting process (Geier and Hood, 1989).

Food engineering research has several characteristics which distinguish

it from other research categories. Most food research is process-oriented, with only a limited knowledge of the mechanisms. Frequently the functional form is unknown. The lack of a theoretical model requires efficient experimental techniques to build an empirical model and find the optimum operating condition. Thus, the experimental results must estimate both a functional form and the parameter values for predicting the response.

In 1962, Berry and his co-workers used RSM to study the production of vinyl starch. The interrelationship of five variables (time, temperature, pressure, base and solvent ratio) were determined by employing a central composite rotatable second-order response surface design. A comparison of predicted and observed value for the degree of substitution indicated that the response surface design is a good characterization of the relationship between the variables and degree of substitution. Two steel compression cylinders, each containing a floating piston and an internal volume of approximately 2 liters, were used in parallel in the experiment (Berry and al, 1962).

Happer and Wanninger applied RSM to optimize a cereal toasting manufacturing process. The objective of the study was to determine the effect of the toaster's operation on the finished product flavor, color and specific volume. Raw product moisture, toaster conveying belt speed, toaster temperature and fan speed governing the hot air velocity were tested as independent variables (Happer and Wanninger, 1970).

Aguilera and Kosikowski successfully used RSM to analyze a soybean extruded product process. In this experiment, the effect of three variables, each in three levels, process temperature (120, 145 and 170° C), feed

moisture content (20, 30 and 40%), and screw speed (800, 900 and 1000 rpm) were studied relative to their extrusive characteristics. The objective of this study was to explore RSM as a tool for a better understanding of the relationship between extrusion conditions and product characteristics and as a means for optimizing the process through the simultaneous analysis of temperature, feed moisture content and screw speed. A fractional factorial design with three replicates at the center point was used for this experiment. Runs were performed randomly in a 5-head Wenger X-5 extruder (Aguilera and Kosikowaski, 1975).

Box introduced Evolution Operation (EVOP) to a full-scale food plant. As an example, the yield of the lobster manufacturing plant was studied by means of EVOP, and the length of claws and pressure between claws were considered as independent variables. Box indicated that the technique has been used with particular success in the chemical industry for many years but is capable of wider application in the process industries generally (Box, 1975).

In 1976, Smith and his co-workers used RSM as a tool to evaluate the effect of three variables, homogenization temperature (50, 60, 70 °C), pressure (1000, 1500, 2000 psi) and emulsifier concentration, on the physical stability of 25% milk fat emulsions in three different series. The equipment used for sample homogenization consisted of a high-pressure, controlled-volume pump, a manometer and a parallel-flow heat exchanger. The experiment used a three variable, three-level central composite design. Stability index data were analyzed for multiple regression using a Burroughs 6700 computer and a standard statistical computer package (Dixon, 1970).

The ten regression coefficients were fed into a Taktronics 4010 terminal to develop graphical plots on the display screen using the UCDRSM program written in Fortran (Smith and et. al, 1976).

In 1980, the Response Surface Methodology and the Path of Steepest Ascent were used in rapidly determining optimum conditions for whipping a full-fat soy protein produced by ultrafiltration. Four independent variables, protein concentration (3.5-4.0%), sugar (1.67% w/w), whipping speed (150 rpm) and whipping time (3.5-4 min) were considered to optimize the response variables, overrun and stability, respectively. A 2^4 fractional factorial design was taken in the experiment to determine the initial Path of Steepest Ascent (Lah, Munir and Richard, 1980).

In 1984, RSM was applied to a boneless ham processing system in which three processing variables (tumbling, tenderization and temperature) were optimized for cooked yield (Motycka, Devor and Bechtel, 1984). A 2^3 factorial experiment with replicated center points, Path of Steepest Ascent and central composite design were performed for both pre- and post-rigor muscle, respectively. In the experiment, a mechanical tenderizer was used to tenderize the meat and the tumbling of the meat chunks was accomplished with a Universal 190 Inject Star Tumbler operated continuously with vacuum (584-660 mm Hg gauge).

Oh, Seib and Chung (1985) used RSM to examine the effects of five variables on the quality of oriental dry noodles. A response surface design described by Cochran and Cox (1957) was used to study the relative contribution of a variable to noodle quality and to determine the optimum level for each variable in the noodle-making process. Following preliminary

trials, five independent variables were selected, water absorption (30-80 %, 14% mb), dough pH (4.0-10.0), mixing time (2-10 min), roll speed (4-20 rpm), and reduction percentage in roll gap (10-50 %). Seven dependent variables were measured for each treatment: color and breaking stress for uncooked noodles and surface firmness, cutting stress, resistance to compression, cooked weight, and cooking loss for cooked noodles. The optimum conditions for preparing dry noodles were obtained by superimposing contour plots. The acceptable limits for noodle quality were based on four commercial noodles from Japan, Korea and Singapore.

Floros and Chinnan (1987) used RSM to evaluate the effect of lye concentration (4 to 12% NaHO), process temperature (80 to 100° C) and time (1.5 to 6.5 min.) on the yield, peeling loss and unpeeled skin in a lye-peeling process of pimienta peppers. Optimization of the process was performed to maximize removal of the skin with minimum loss of edible fruit. In the research, they used the Box-Behnken design with three variables, each in three levels.

Later, they applied RSM to a double-stage peeling process for Pimiento Peppers. In this experiment, the optimum processing condition (total removal of the skin, minimum peeling loss, maximum product yield and highest texture values) were studied and the effect of seven factors (pretreatment concentration, pretreatment temperature, pretreatment time, holding time, post-treatment concentration, post-treatment temperature and post-treatment time) on four responses (unpeeled skin, peeling loss, product yield and texture) were studied. In this research, they applied the Box-

Behnken design to the seven independent variables, each in three levels and four responses study again. The statistical package (SAS) was used to generate response surface. Since the stationary points were not only located outside the experimental region but also were saddle points, superimposing contours were used to locate optimum conditions for visible aid in both cases above (Floros and Chinnan, 1988).

2.3 Review of Onion Peeling Machines

In this review, attention is focused on outlining the development of the onion peeling machine, defining some essential machine functions or processing steps, and discussing their relationships, as well as, classifying machines into certain types and pointing out their different utilizations. Thereby, a qualitative analysis basis will be built for evaluating the performance of a new type of onion peeling machine. In addition, the merits and demerits of some typical mechanisms were discussed.

The generation and development of an onion peeling machine, just as with any other machine, is determined by the requirements of human beings and mechanical manufacturing abilities.

The onion peeling machine, if we define it as a kind of tool to perform the function of peeling onion skins, is probably as old as the onion itself when human beings ate it as a type of vegetable. In the earliest days, onion peeling was done with a hand-held knife. At that time, a hand-held knife probably satisfactory for a family's, or even for a tribe's requirements to peel a small number of onions to eat as a food or used to cure diseases

as medicines. Later, however, with the development of human activities, the onion played an increasingly important role in human life. All kinds of onion products, such as, onion powder, onion oil, onion juice, fresh onions, dehydrated onions and canned onions were brought to market. At that time, a hand-held knife did not satisfy people's needs to process a large number of onions quickly. They needed equipment to treat onions in a more effective way. Human beings' demands determined the invention of the onion peeling machine and the types of machine which would be developed. Therefore, processing capacity and efficiency are two important specifications which are closely related in the development of onion peeling machine.

Today, in modern food processing factories and professional onion peeling plants, onions can be processed automatically from raw onion to onion products in a procedure in which onions are automatically loaded, oriented, cut, slitted, peeled, washed and sliced or chopped.

As a type of tool, the onion peeling machine meets a need for certain processing technologies in order to produce desired products. Many technologies are applied in producing onion products. Onion peeling is the first important step in these process technologies. The major onion peeling processing technologies used in practice are hand peeling, lye peeling, flame peeling and machine peeling.

Lye peeling and flame peeling are rough processing technologies which are suitable for preparing onions only for some products. In lye peeling and flame peeling, onions are abraded and treated in a hot solution of caustic soda or burnt by passing through a furnace. In these processes,

burnt skins are removed by scrubbing them either with brusher or passing them through a continuous type abrasive peeler or rotating them in an abrasive drum similar in operation to a potato peeler. These methods suffer from a number of disadvantages. First, they produce incompletely peeled onions, that is, the core of root remains with the fleshy onion bulbs. For some onion products this kind of onion is not acceptable and it needs to be processed further. In addition, the peels must be thrown away; they cannot be used to produce by-products. So, these technologies are relatively costly and inefficient. Moreover, they tend to damage the onions and their flavor. And, in general, they are messy, thereby, creating uncongenial working conditions. In order to overcome the disadvantages mentioned above and to meet the increasing demands for peeled onions, in the last 100 years, many onion peeling methods and corresponding equipments have been developed.

According to incomplete statistics, roughly estimated, since the development of technologies in agriculture and industry, onion machine peeling technology has its genesis in the early 1900s. It is a type of purely physical treatment method, safe, low cost, and highly efficient. In the technology, there is no pollution or chemical damage in onion products. It is a complete peeling method in that it peels the outer layer and cuts off the core of root from onions, and the peeled portions can be recycled to produce other onion products. This technology not only meets the needs of large batch processes, but also flexibly meets small and medium batch processes, so it is widely utilized in the food processing industry.

It is estimated that about one hundred onion peeling machines and

related methods had been developed and granted U. S. Patents according to the survey from 1890 to 1990. If we include many countries which did not file patents in the United States in this period, we conservatively estimate that in the past century, more than 200 onion machine peeling technologies and equipment have been developed in the world.

The main reason there are so many types of onion peeling machines in the world is due to the character of the onion itself. Because the onion is a type of bulb-like vegetation, its numerous varieties, shapes and sizes as well as its many different applications require onion products producers to prepare onions in many different ways. For instance, in some Asian countries, pickled onion is favorite food, for which small size dry onion, just needs to be cleaned and peeled of its outer dry layer before preserving. The Patent 4,457,224 (1982), *Apparatus for Stripping Onion*, filed by Kino for Fuji Foods Engineering Co. Ltd. in Yokohama, Japan, is probably designed just for this type of application. The schema of the machine is shown in Figure 3. Another example is the onion ring, a type of popular food in the United States. For onion rings, one must first take off the outer layer and the core of the root from fresh, large-sized onions, and then slice the cleaned flesh bulb. A machine named *Onion Skinning and Slicing Machine*, Patent 2,602,480 (1948), Figure 4, filed by Taylor for Machinery Development, Co., in Idaho, probably was designed for preparing this type of food. Therefore, the design of the onion peeling machines vary with the objective in different applications.

Another reason for the variety of available machines is capacity. The capacity refers to the number of onions the machine can process in a certain

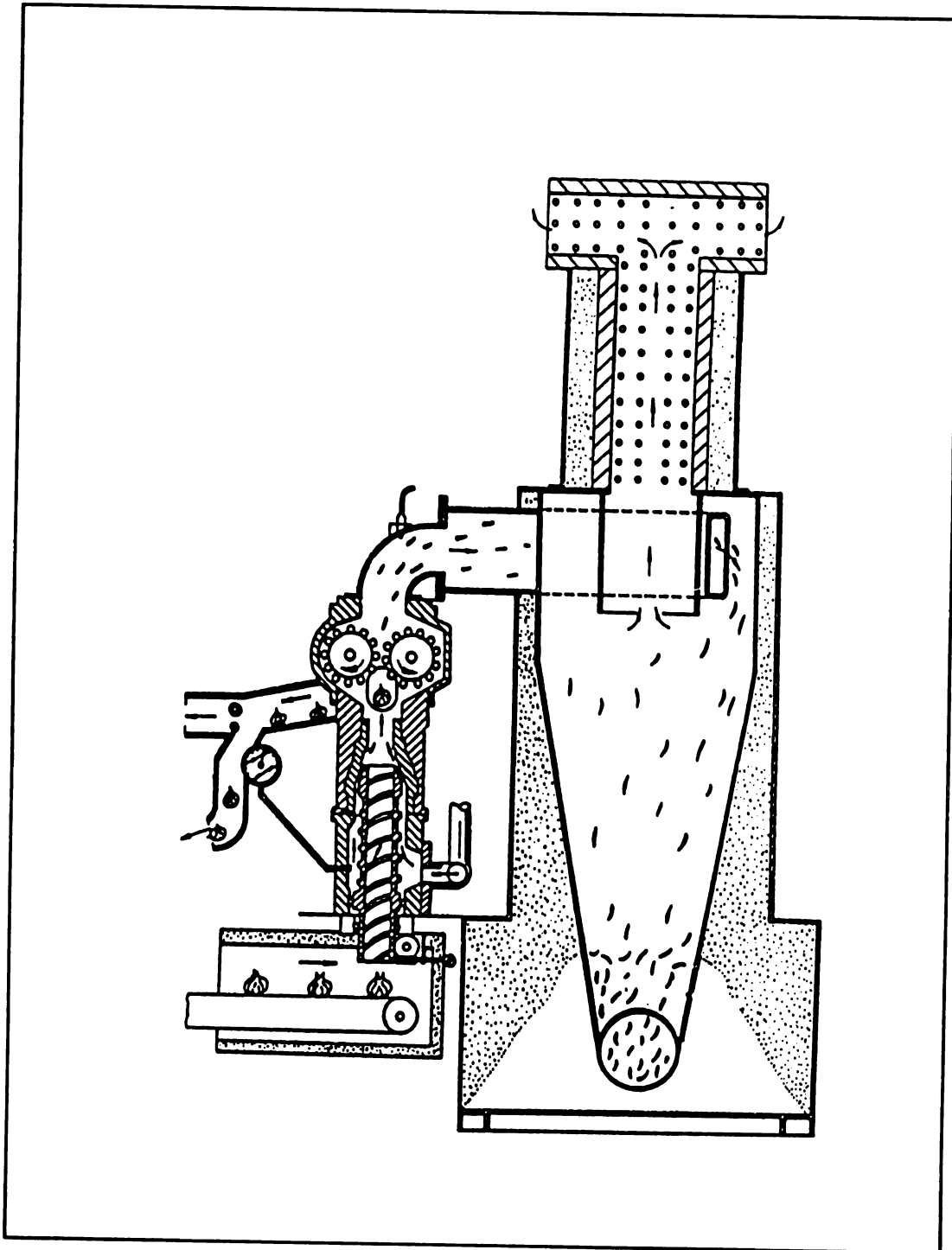
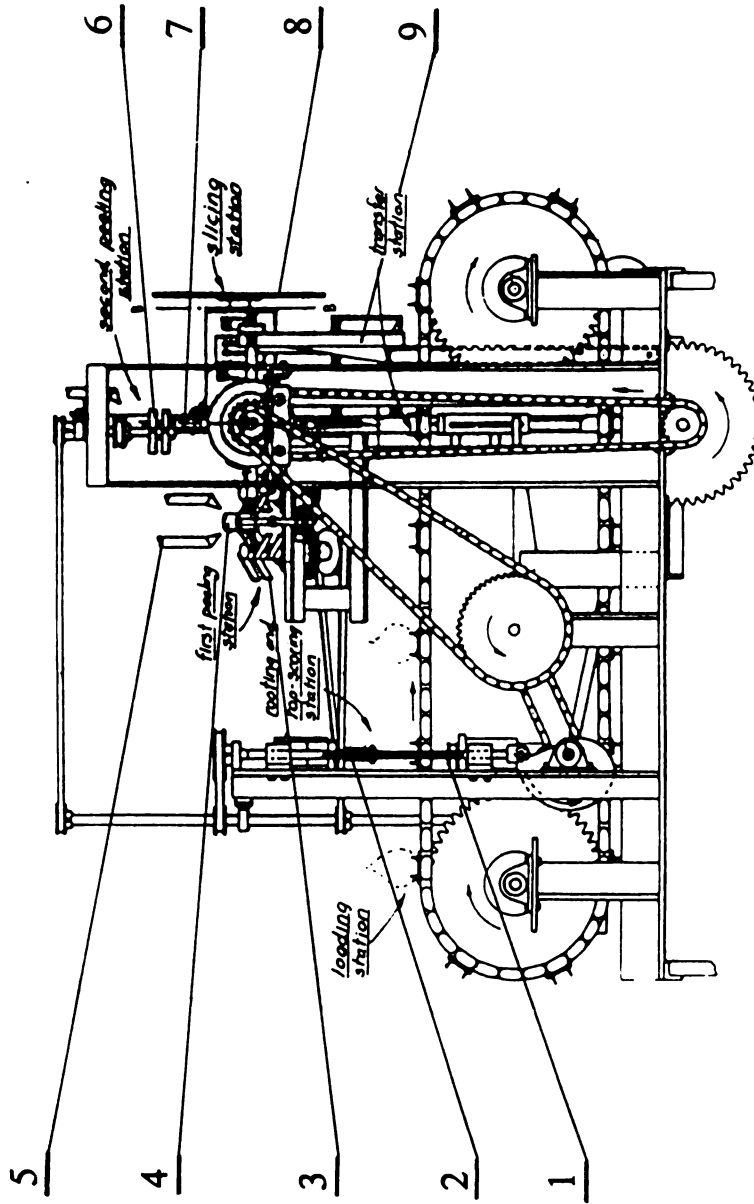
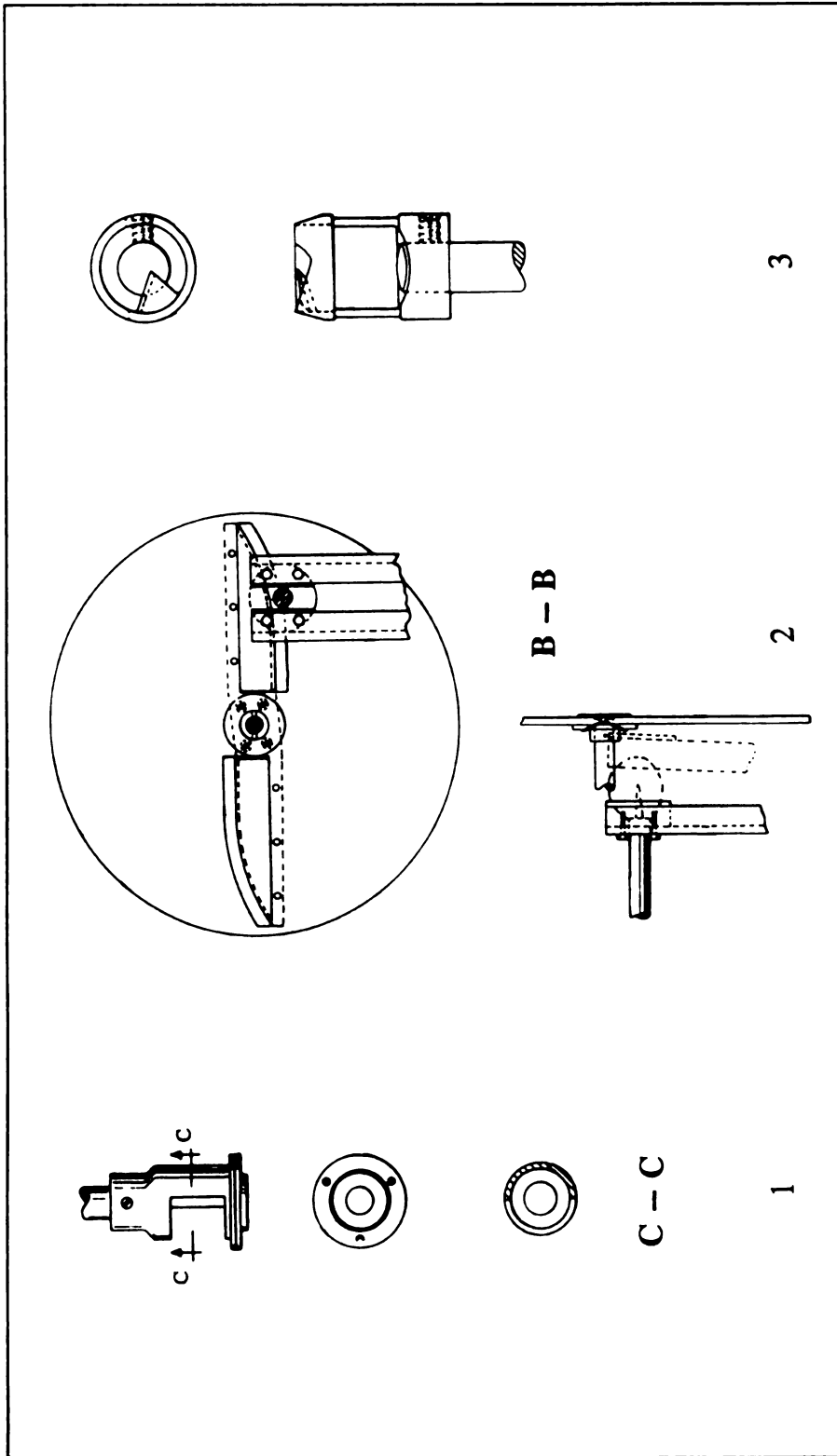


Figure 3 U.S. Patent 4,457,224 Apparatus For Stripping Onions (Kino, 1982)



1. Root cutting knife 2. Top-scoring knife 3. Flexible straps 4. Fix blade 5. Steam jet
6. Erasing straps 7. Spindles 8. Slicing knife 9. Crowder arm

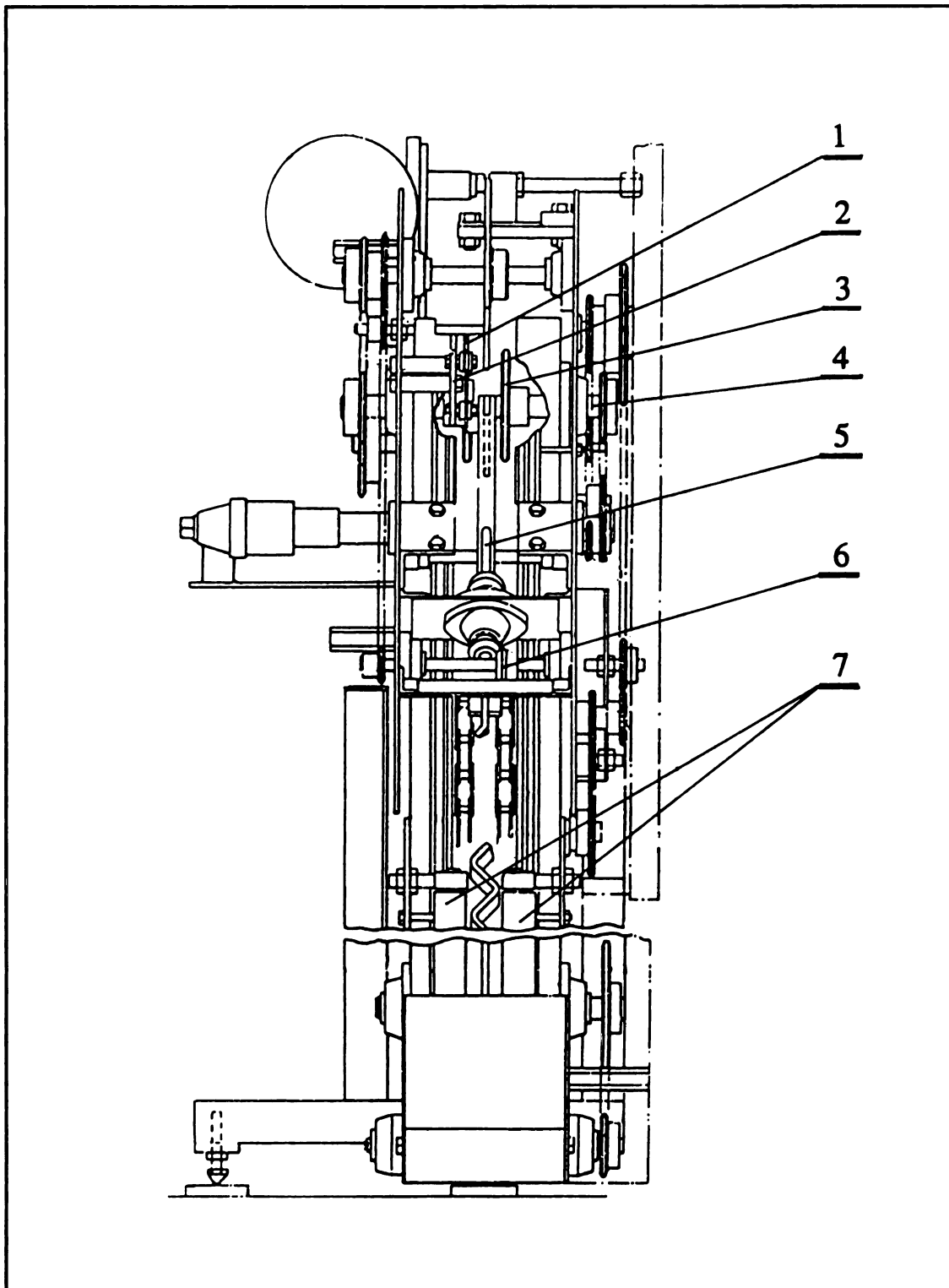
Figure 4 U.S. Patent 2,602,480 Onion Skinning and Slicing Machine (Taylor, 1948)



1. Top cutting knife 2. A sectional view taken on line B-B of Fig. 2.7 showing the rotary slicing knife in elevation and the action of the crowder element which forces an onion against the rotary slicing knife 3. Root cutting knife

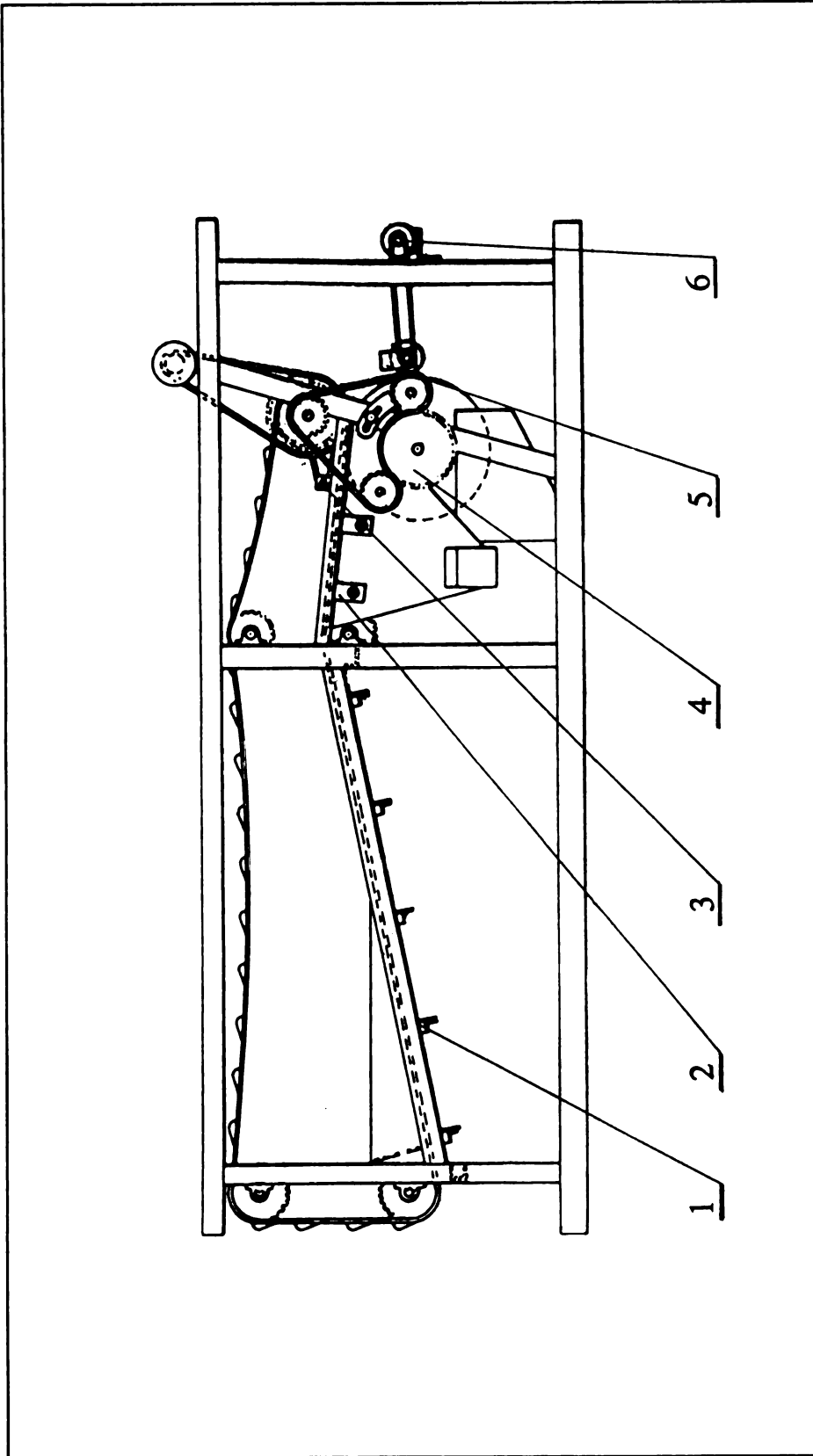
Figure 4A The structure of knives in TAYLOR Machine (1948)

time. For example, a canning company needs a large-capacity onion peeling machine to process large volume of onions, three shifts a day, while small businesses, such as a fresh onion products suppliers need just a small or medium capacity machine to process onions periodically. In general, there are two types of onion peeling machines classified mainly by their capacities, the industrial onion peeling machine and the farm onion peeling machine. The best-known industrial onion peeling machines are: PARSONS Machine, Figure 5, (Les. Parsons & Sons Limited, Burry Port, South Wales, Great Britain, 1970). AGUILAR Machine, Figure 6, (Basic Vegetable Products, Inc., Henry Aguilar, San Francisco, Calif., 1967). ORLOWSKI Machine, Figure 7, (Korlow Corporation, Chicago, Ill., 1969). MELLON Machine, Figure 8, (Marriott Corporation, Montgomery County, Maryland, 1970). GREEN Machine, Figure 9, (Ore-Ida Foods, Inc., Boise, Idaho, 1975) and TOYOSATO Machine, Figure 10, (M. G. I. Co., Ltd., Kanagawa, Japan, 1982). Usually, they have large and complex construction, high automation devices, and powerful transmission and electrical control systems. They possess the ability to deal with a large volume of onions in a relatively short time. However, they are expensive, and not easy to operate and they need professional maintenance. The best-known farm onion peeling machines are: URSCHER Machine, Figure 11, (J. R. Urschel and G. W. Urschel, Valparaiso, Ind., 1944). BOYER Machine, Figure 12, (Barrier Center, N. Y., 1958). BUCK Machine, Figure 13, (Tripax Engineering Company Proprietary Limited, Victoria, Australia, 1968). ROOD Machine, Figure 14, (Michigan Fruit Canners, Inc., Benton Harbor, Mich., 1971). BOYER Machine, Figure 15, (4826 Oak Orchard Rd., Albion, N. Y. 14411, 1973). CLYMA Machine, Figure



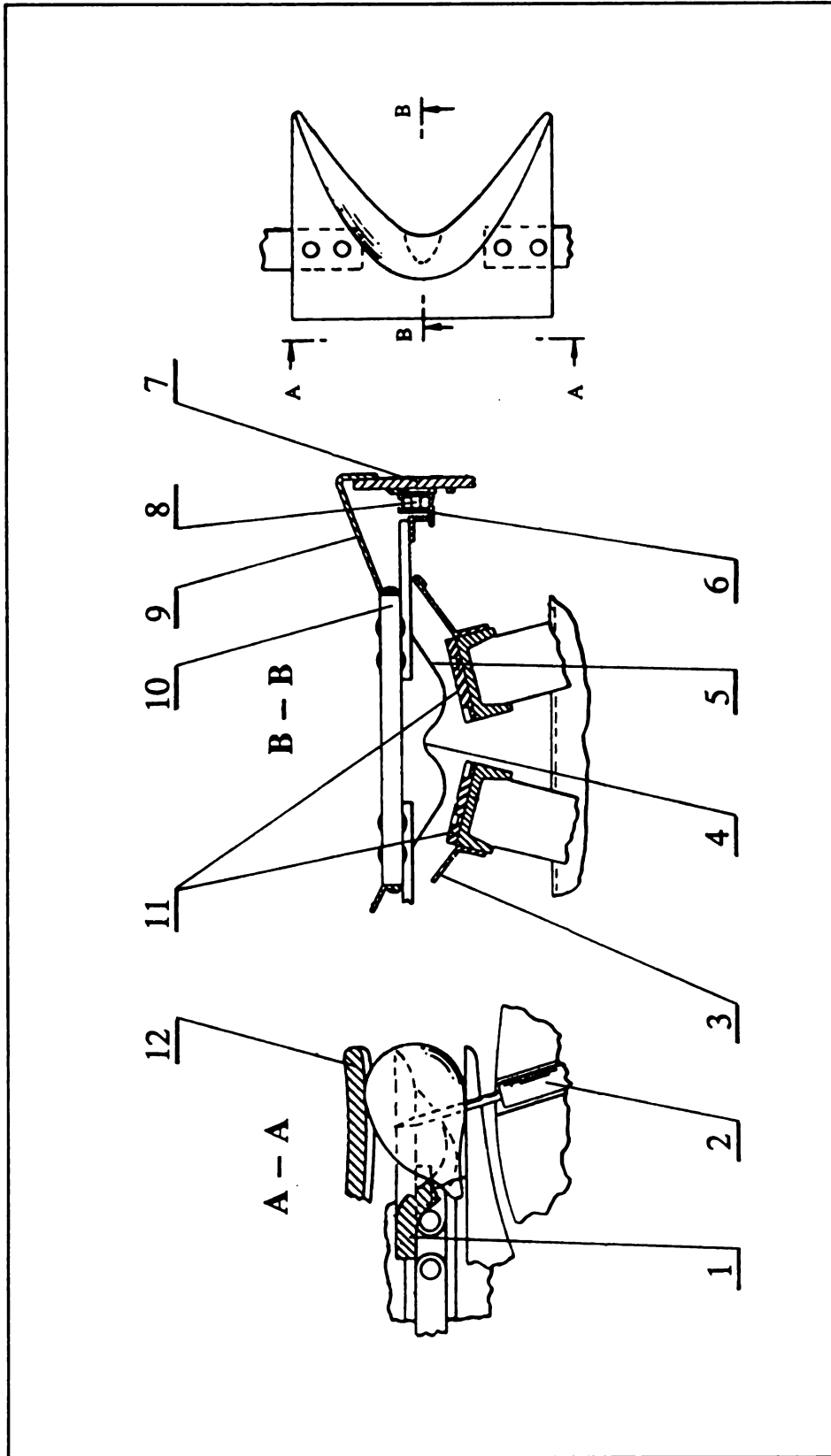
1. Slide 2. Frictionless slide 3. Conveyor 4. Transverse shaft
5. Transverse blade 6. Bevel 7. Two eccentric rollers

Figure 5 U.S. Patent 3,724,362 Article Feeding And Treating Apparatus (Parsons, 1970)



1. Friction strip element 2. Central onion supporting rail 3. Hold-down mechanism 4. Transfer mechanism 5. Cutting blades 6. Motor

Figure 6 U.S. Patent 3,515,193 Onion Orienter and Cutter (Aguilar, 1967)



1. Upper portion 2. Tines 3. Wall 4. Opening recess 5. Downwardly projecting portion
6. Guide strip 7. Chain 8. Strip 9. Wall 10. Supporting bar 11. Friction strips 12. Hold-down arm

Figure 6A The structure of oriental component AGUILAR (1967)

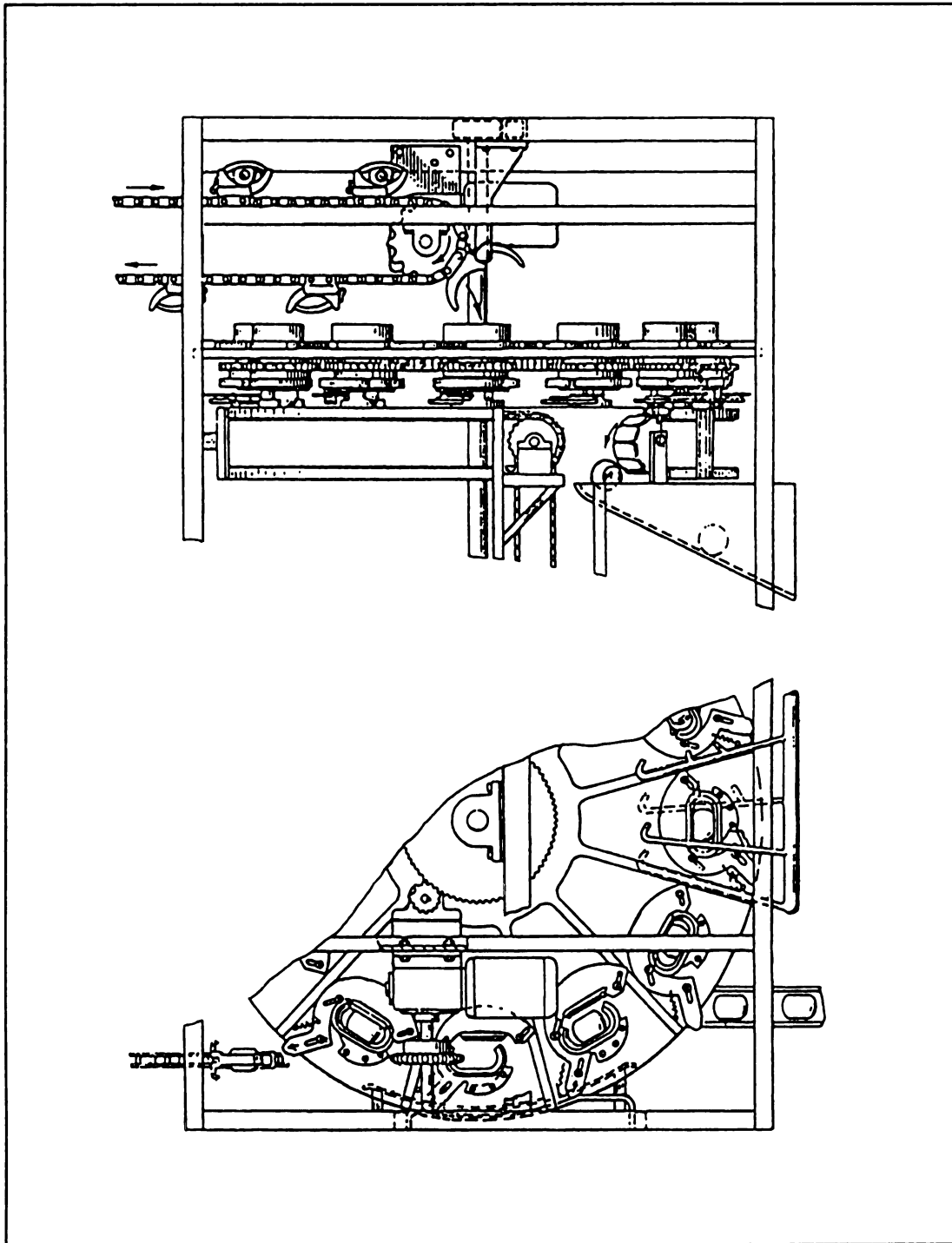
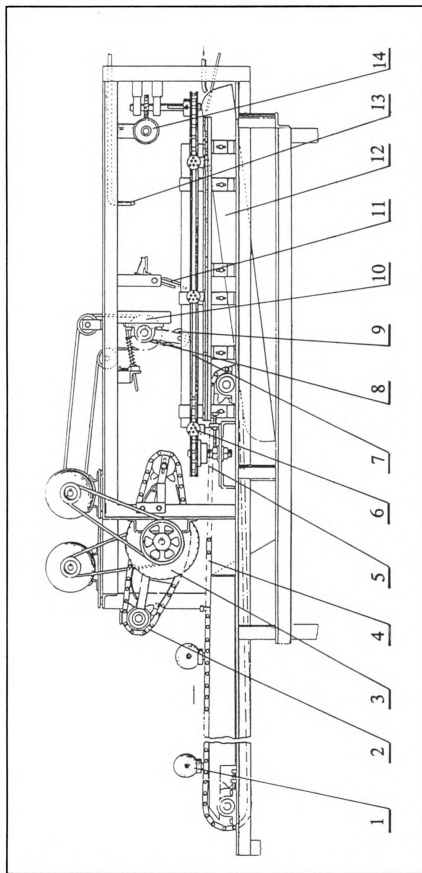


Figure 7 U.S. Patent 3,606.917 Peeling Machine (Orlowski, 1969)



1. Cylindrical cup 2. Hold-down section 3. End cutting discs 4. Longitudinal cutting assembly 5. Transfer section 6. Onion engaging member 7. Stationary teeth track 8. Chain 9. Slitting blade 10. Pulley 11. Air jet nozzle 12. Tray 13. Water nozzle 14. Worm gear

Figure 8 U.S. Patent 3,696,848 Method And Apparatus For Removing Skin From Onions Or Like Vegetables (Mellon, 1970)

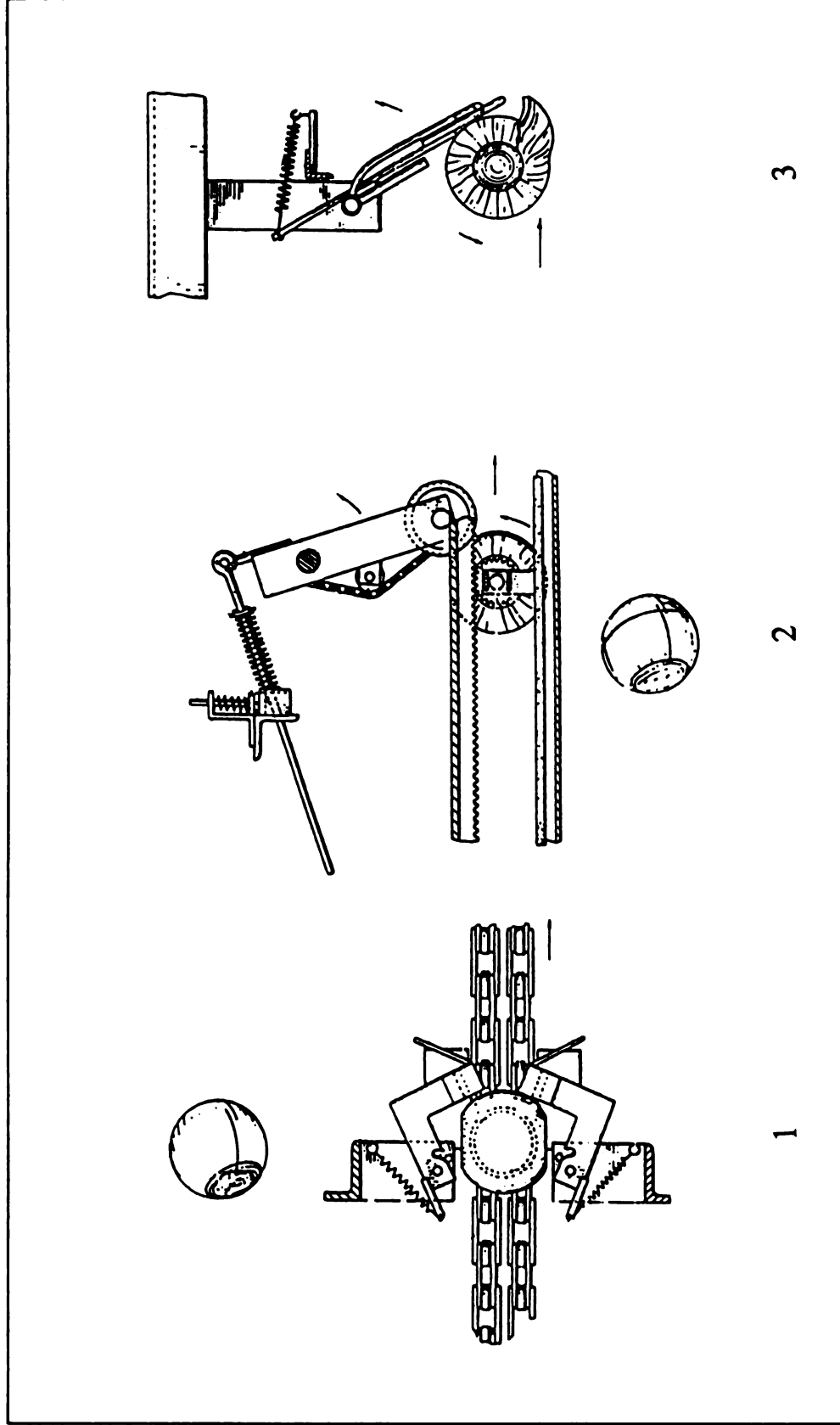
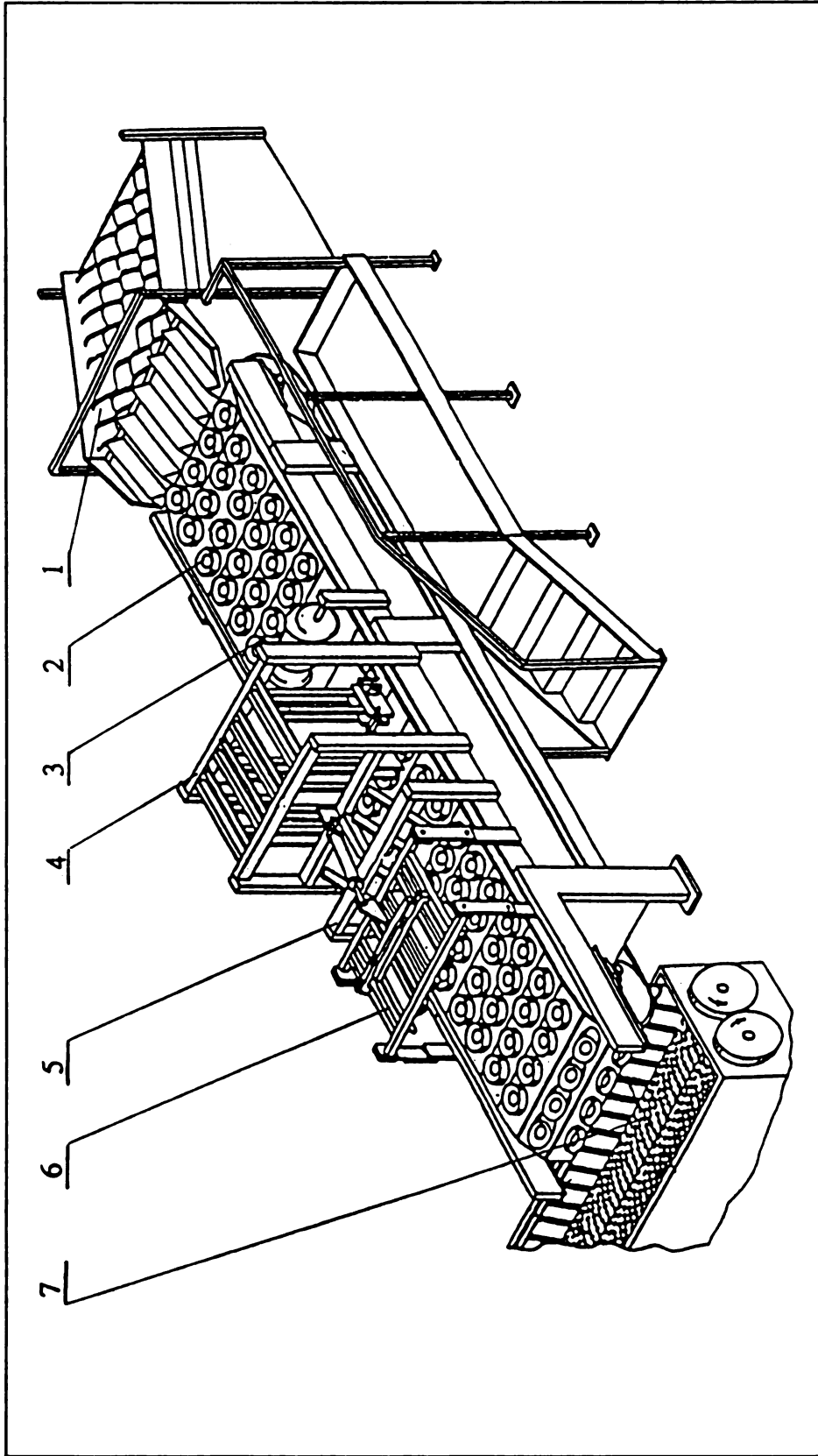


Figure 8A The structure of slitting and peeling mechanism of MELLON Machine (1970)



1. Shufflo Feeder 2. Cup-Type Conveyor 3. Impaling Section 4. Root and Stem Cutting Section 5. Slitting Section 6. Stripping Section 7. Separating Section

Figure 9 U.S. Patent 4,068,011 Method Of Peeling By Scalding And Cutting (Green, 1975)

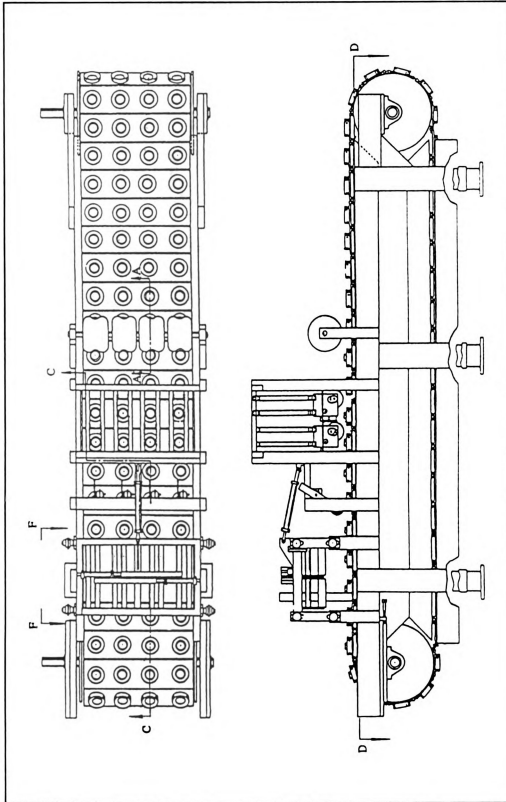
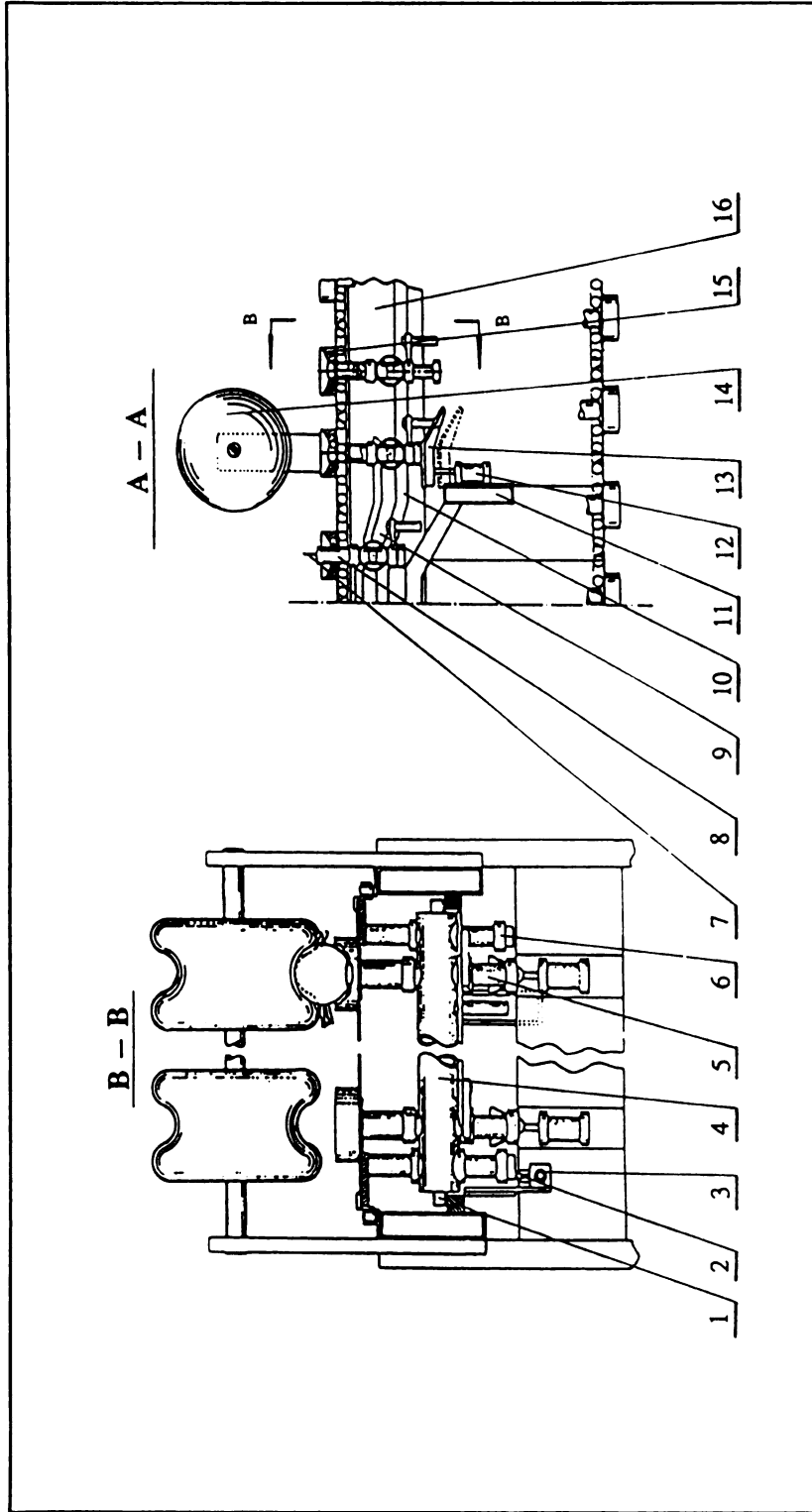
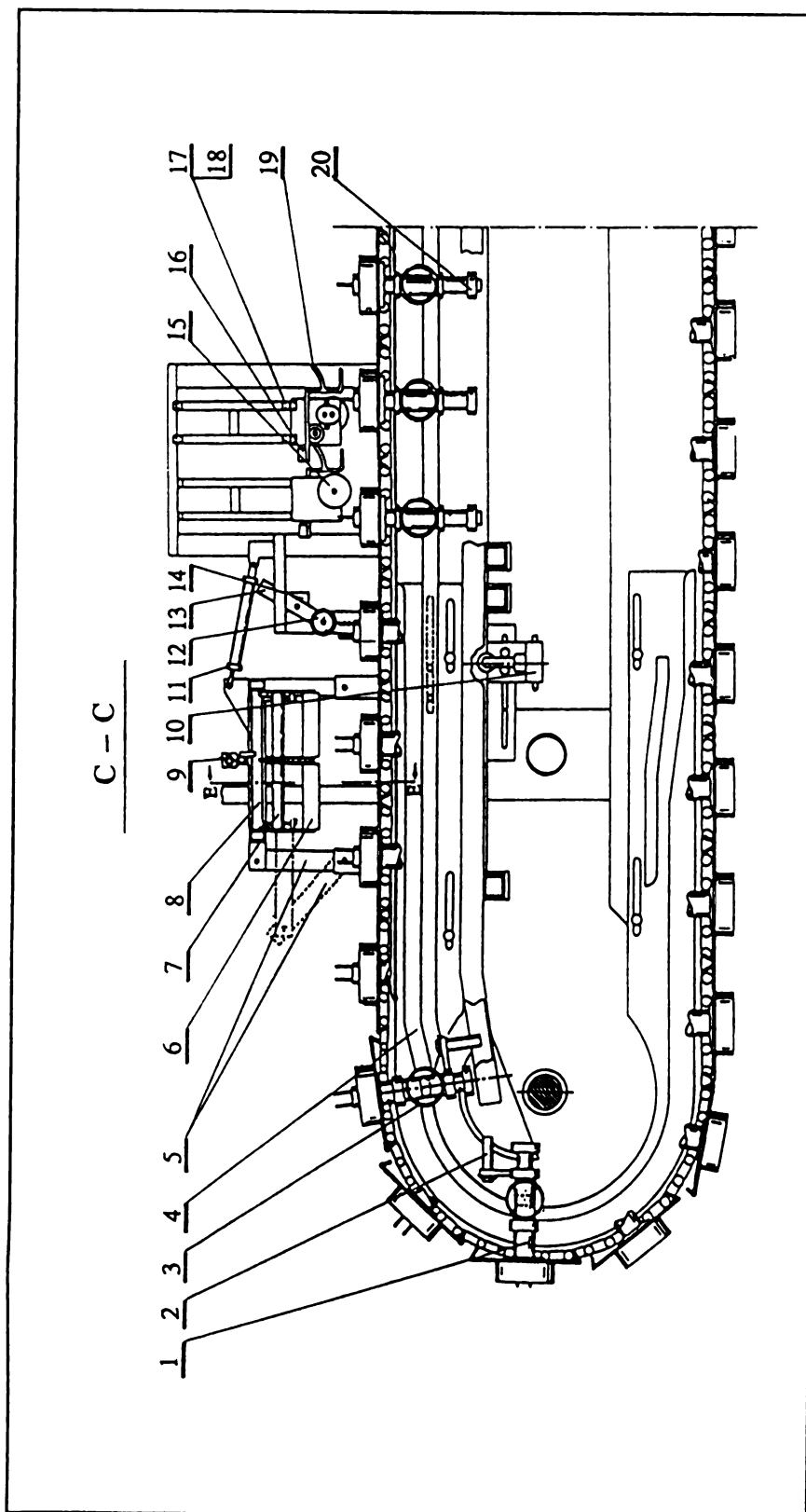


Figure 9A A Top Plan View and Side Elevation of Green Machine (1975)
(Excluding feeder and separator)



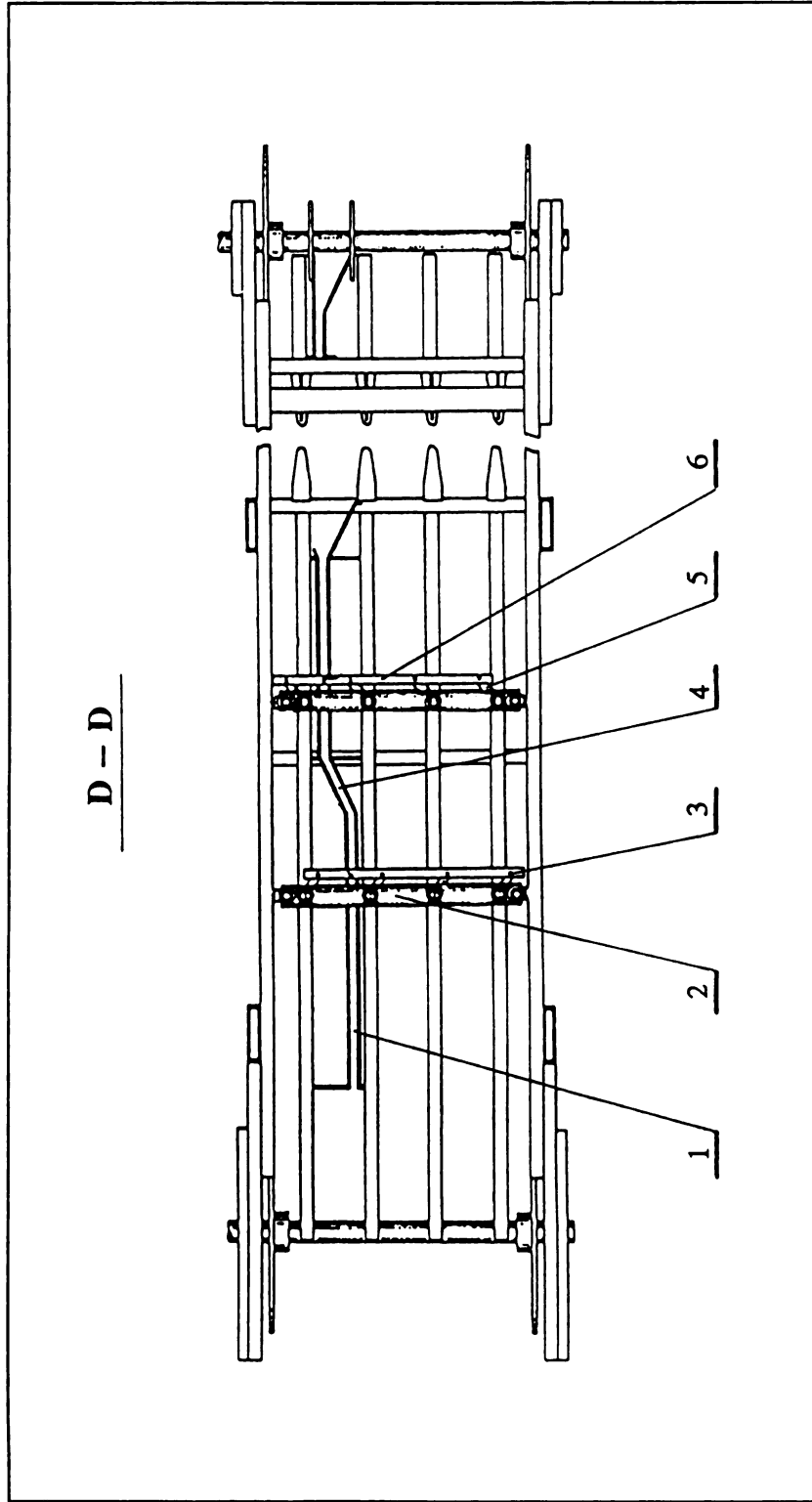
1. Cam follower member 2. Operating lever of control valve 3. Control valve of power cylinder 4. Transversely Extending support 5. Forcibly raising piston 6. Valve actuator 7. Tine 8. Pedestal 9. Upwardly inclined portion of cam-track 10. Cam-track 11. Transverse beam member 12. Power cylinder 13. Platform 14. Roller 15. Cup 16. Structural Frame member

Figure 9B A fragmentary, transverse, vertical section taken on the line A - A of Figure 9A to show the construction of impaling section (Green, 1975)



1. Pedestal 2. Cam follower pin 3. Support element 4. Cam-track 5. Motion frame 6. Gripping jaw
7. Stripper 8. Pivot shaft 9. Power cylinder 10. Dual air valve 11. Power cylinder 12. Rotary cutter
13. Lever 14. Pivotal mounting 15. Paired rotary disc cutter 16. Counterbalance 17. Hinge
18. Elongate frame 19. Feeler 20. Tripper

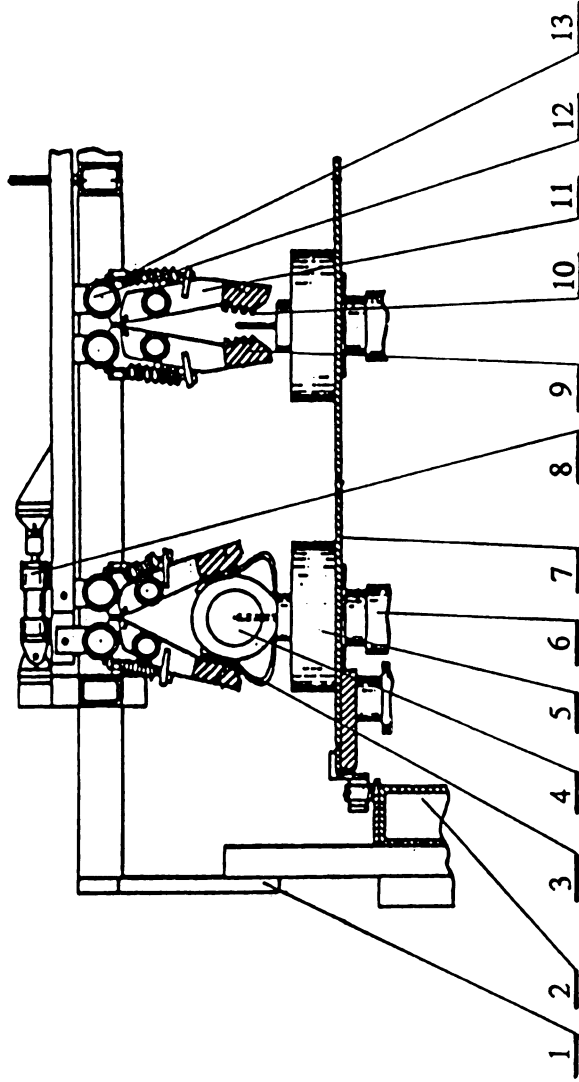
Figure 9C A fragmentary view in longitudinal vertical section as taken on the off-set line C - C of Figure 9A to show the left-hand portion of the machine (Green, 1975)



1. Cam-track 2. Pedestal support 3. Cam follower pin 4. Camming jog 5. Link 6. Bar

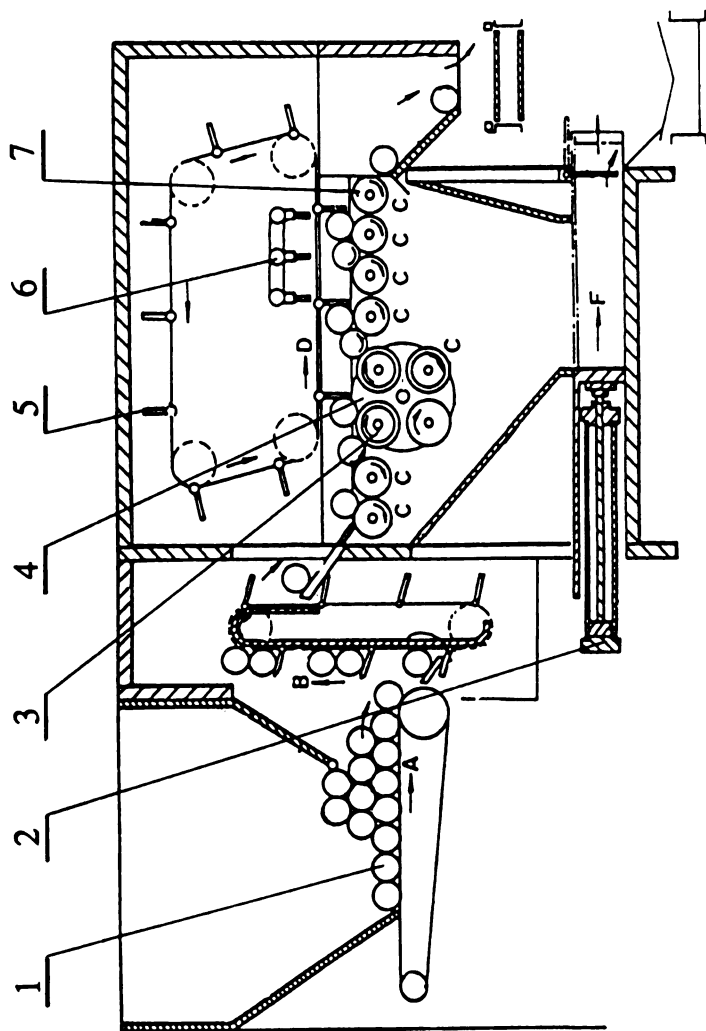
Figure 9D A horizontal section taken on the line D - D of Figure 9A to show the pedestal rotating Mechanism (Green, 1975)
(intermediate parts being broken out for convenience of illustration)

E - E



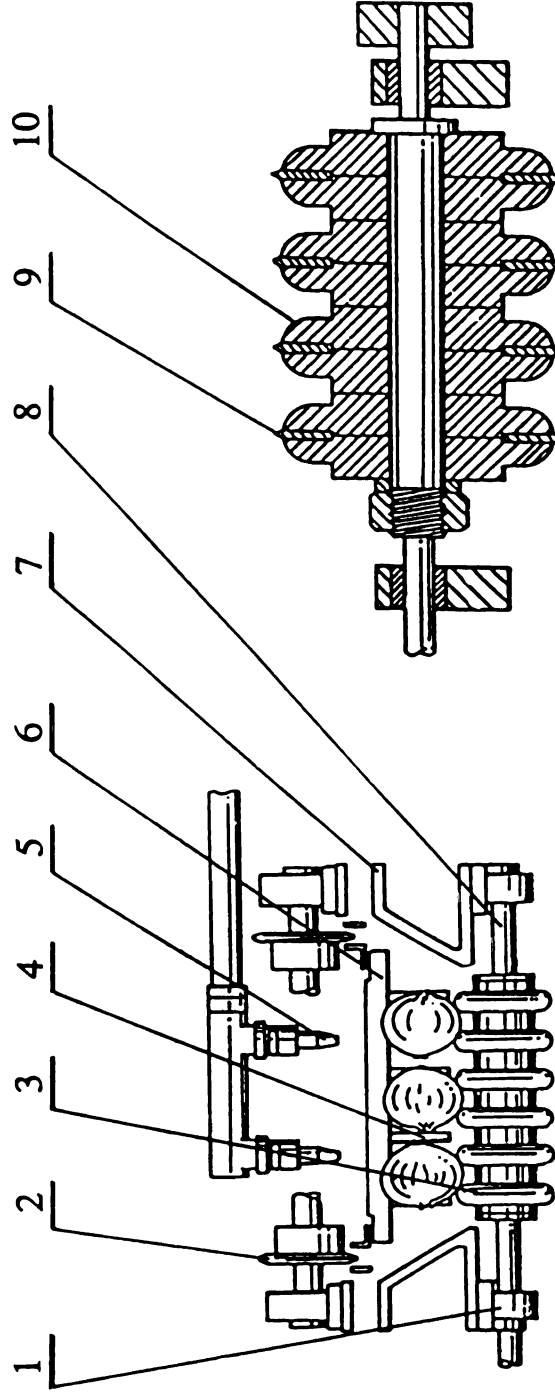
1. Motion Frame 2. Structural Frame 3. Stripping 4. Onion 5. Cup 6. Pedestal 7. Rigid Slat
Section 8. Power Cylinder 9. Gripping Jaw 10. Cornered 11. Stripper 12. Pivot Shaft 13. Spring

**Figure 9E A Fragmentary, Transverse, Vertical Section Taken on the Line E - E of
Figure 9C to Show the Construction of Gripping Section**



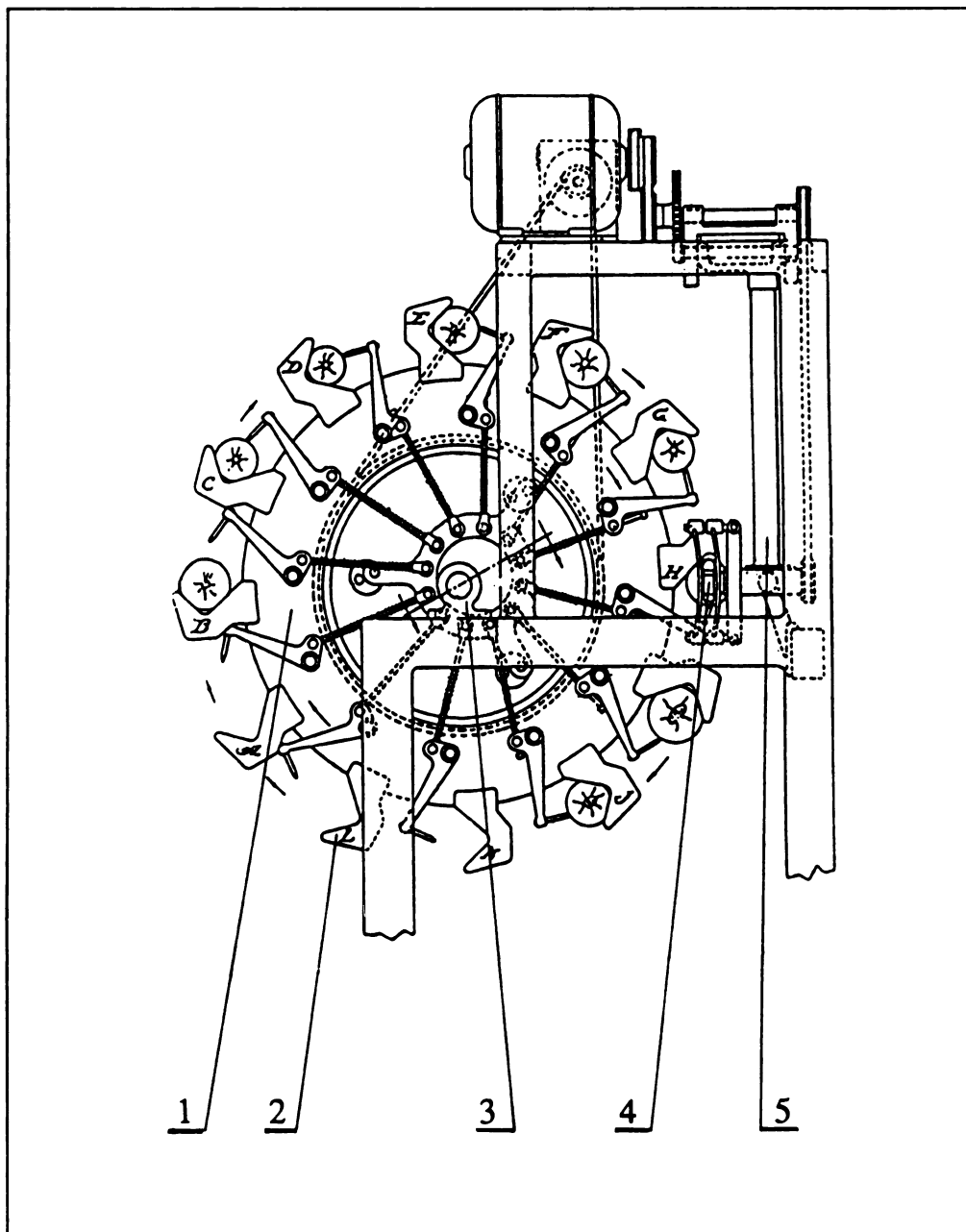
1. Onion 2. Sliding member 3. Rotary saw 4. Fitting plate 5. Com-shaped pawls 6. Air nozzles 7. Roller

Figure 10 U.S. Patent 4,481,875 Bulb Peeling Apparatus (Toyosato, 1982)



1. Bearing 2. Sprocket 3. Fitting disk-shaped member 4. Pawl 5. Nozzle 6. Lateral Bar
7. Guide 8. Rotary shaft 9. Blade 10. Rotary saw

Figure 10A The construction of Cutter and Cutting section of TOYOSATO Machine (1982)



1. Rotating wheel 2. Cradle 3. Clamp mechanism 4. Cutting knife
5. adjustable knife mechanism

**Figure 11 U.S. Patent 2,494,914 Machine For Clipping Onion
And The Like (J. R. Urschel, 1944)**

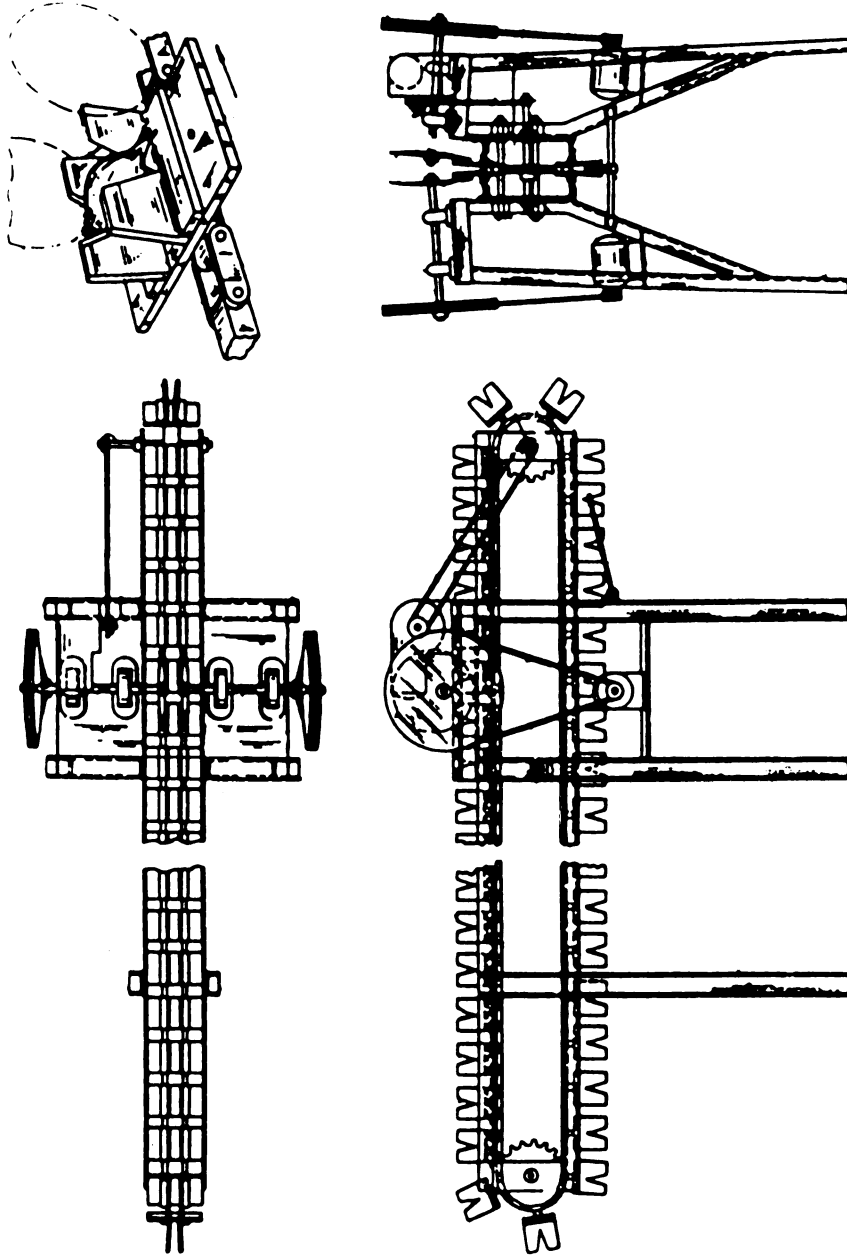
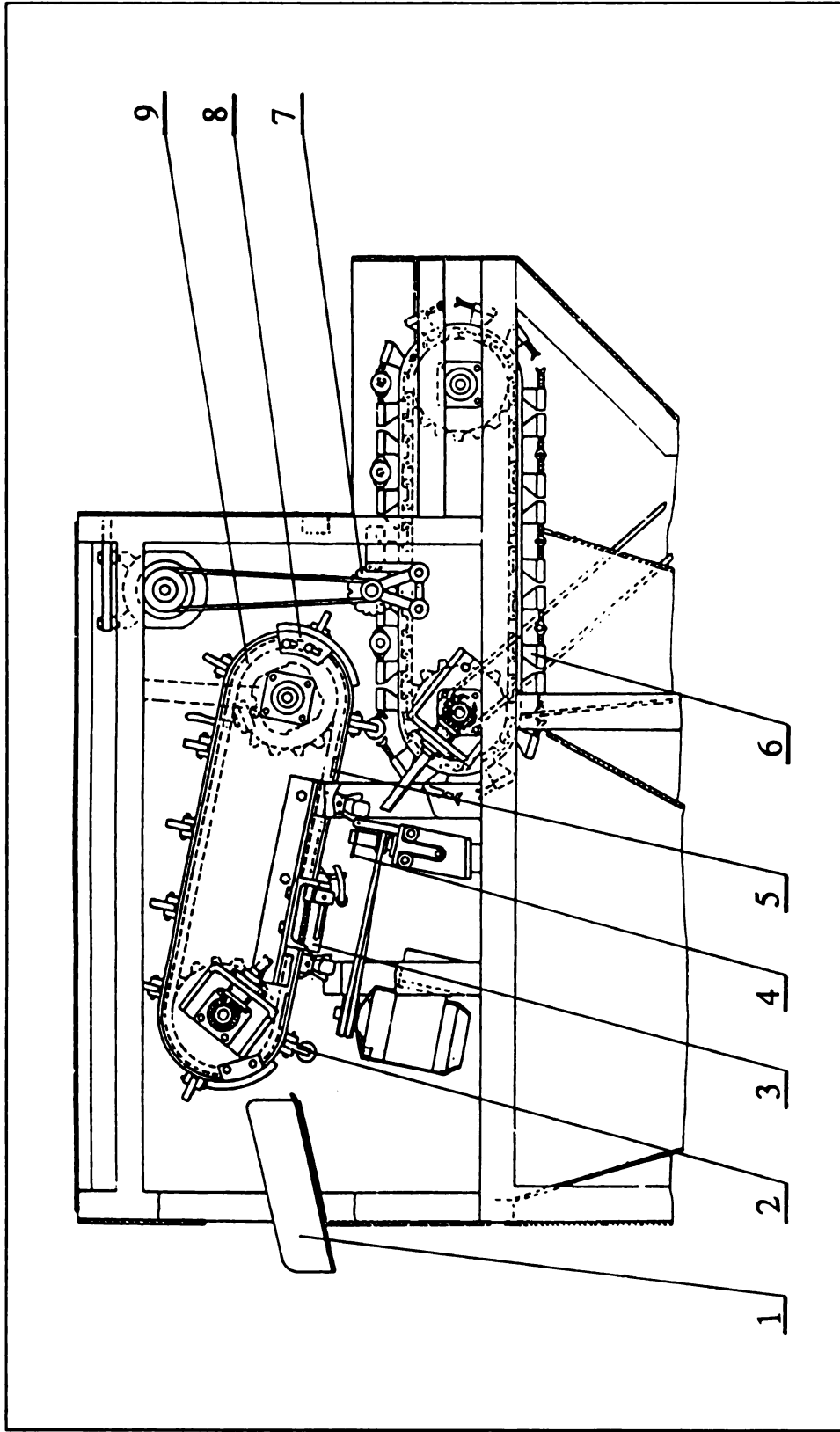
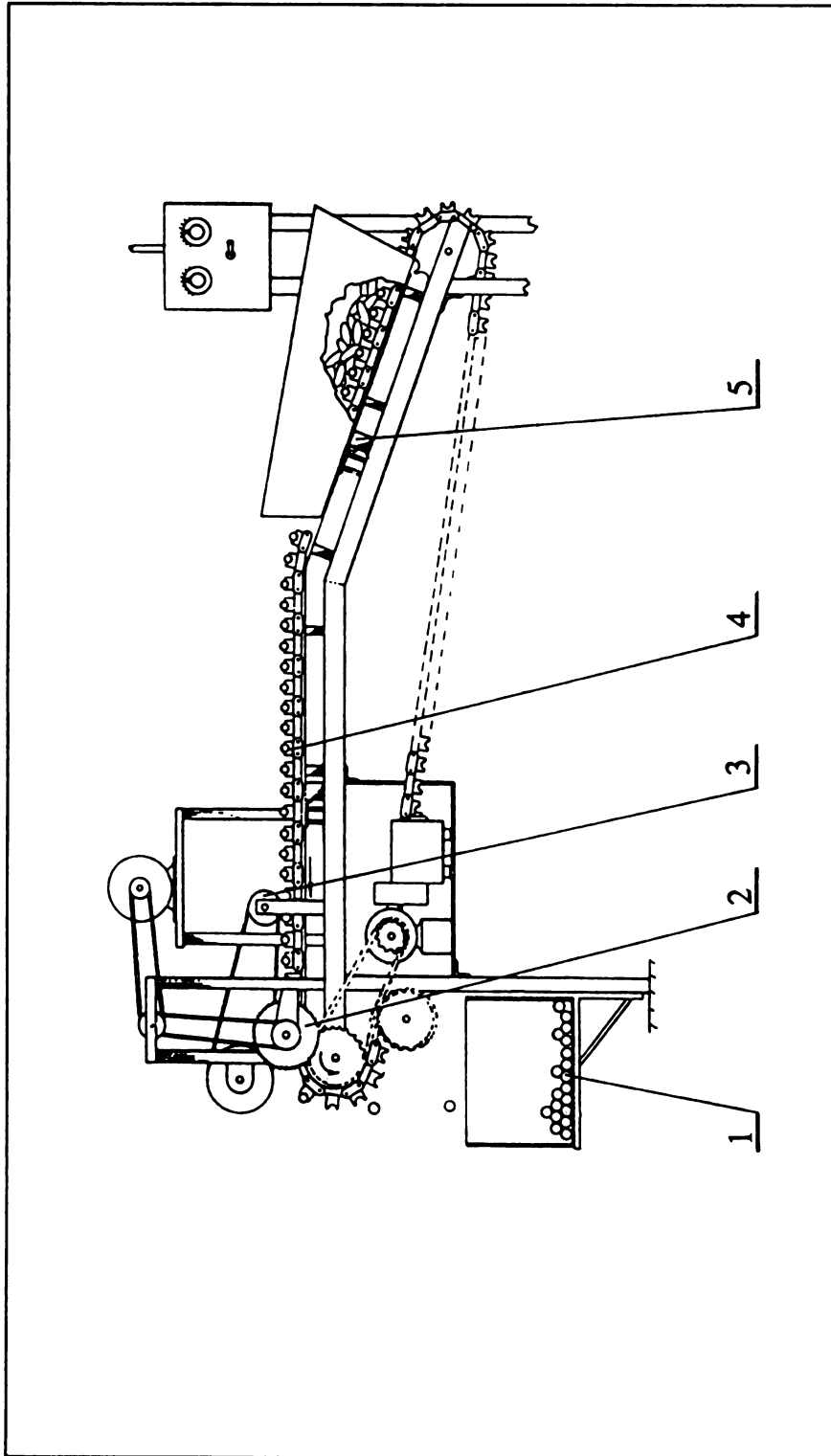


Figure 12 U.S. Patent 2,961,023 Onion Trimming Machine (Boyer, 1958)



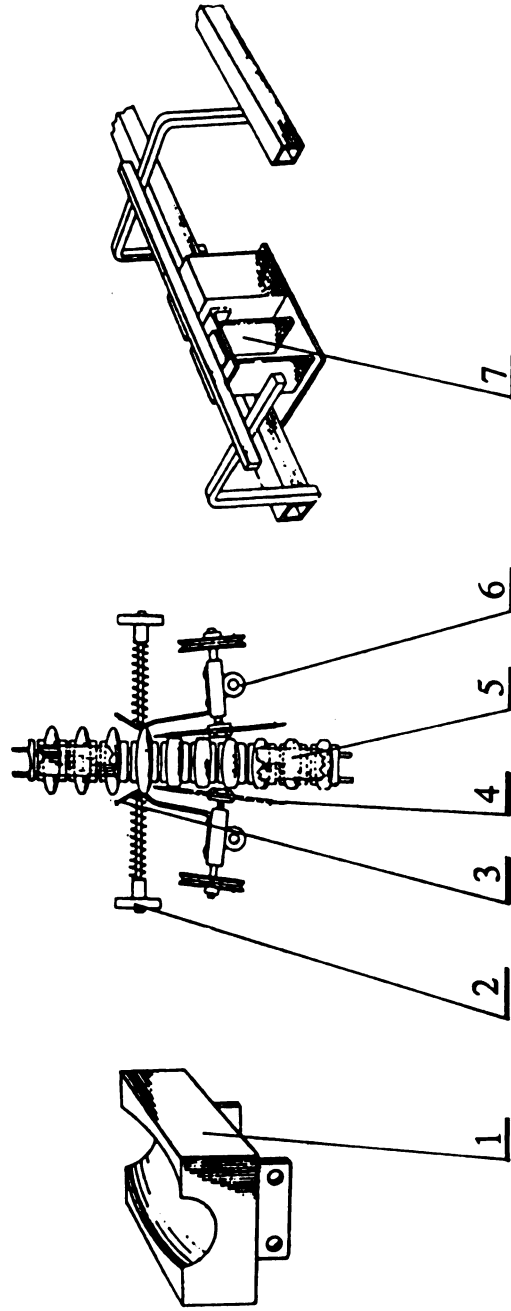
1. Delivery chute 2. Second gripper 3. Air jet assembly 4. Slitting cutter 5. Resilient lug
6. First gripper 7. Cutter 8. Opposed cam plate 9. Track

Figure 13 U.S. Patent 3,623,524 Machine For Preparing Onions (Buck, 1968)



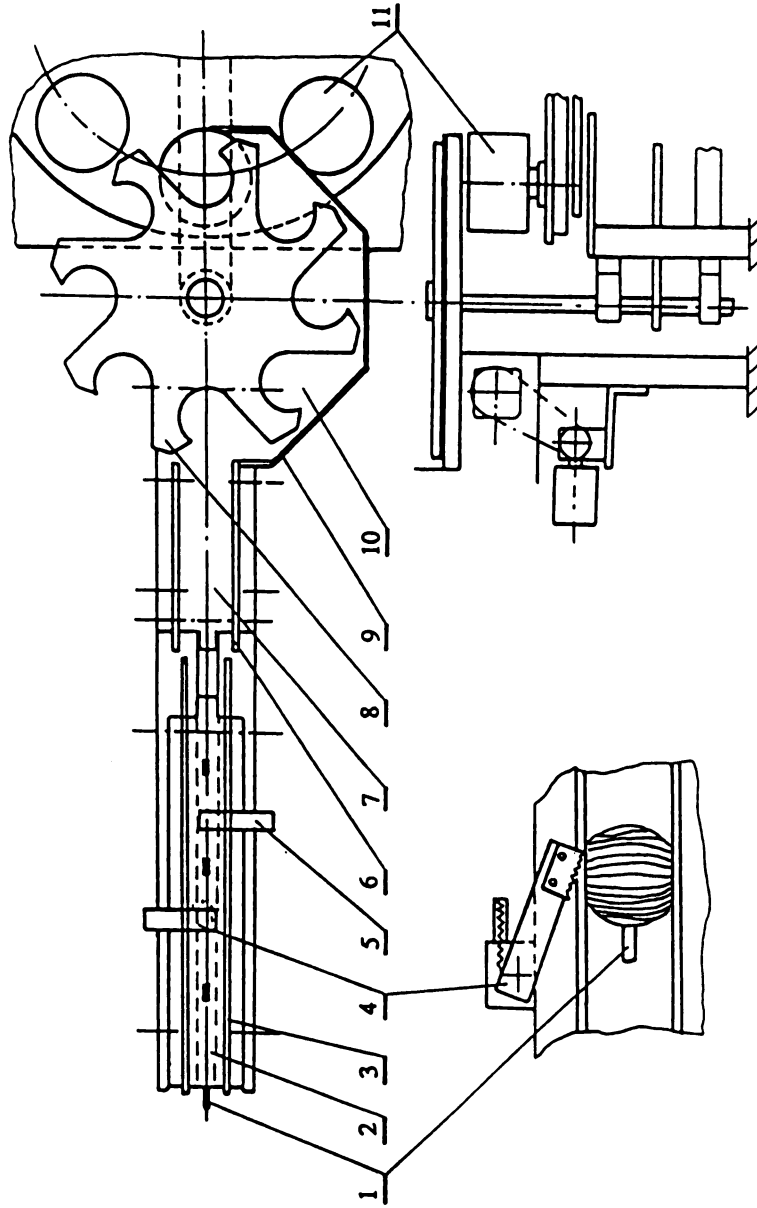
1. Onion 2. Cutting knife 3. Hold-down assembly 4. Onion orienting pocket 5. Vibrator

Figure 14 U.S. Patent 3,764,717 Method For Automatically Orienting And Trimming Vegetables (Rood, 1971)



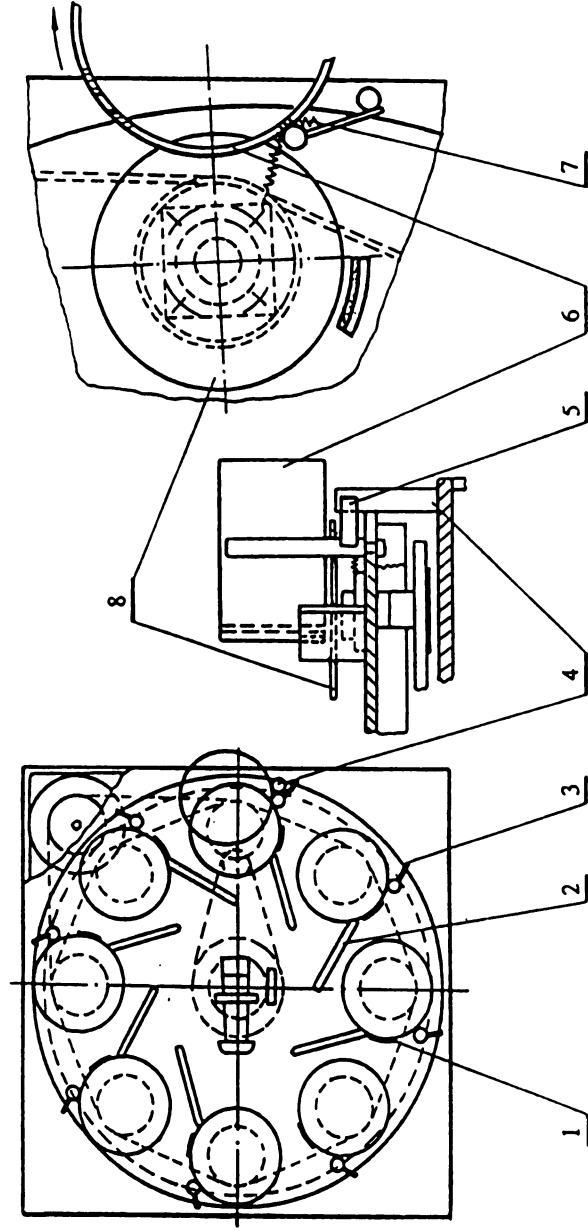
1. Onion orienting pocket 2. Spring biasing mechanism 3. Feeler 4. Cutting knife
5. Hold-down belt 6. Roller 7. Vibrator

Figure 14A The structure of cutting and vibrating mechanism of ROOD Machine (1971)



1. Pushers 2. First Conveyor 3. Retaining Rail 4. First Arm 5. Second Arm 6. Restraining Plate
7. Second Conveyor 8. Pocket Wheel 9. Tray 10. Pockets 11. Cans

Figure 15 U.S. Patent 3,861,295 Slitting and timing section of BOYER Machine (1973)



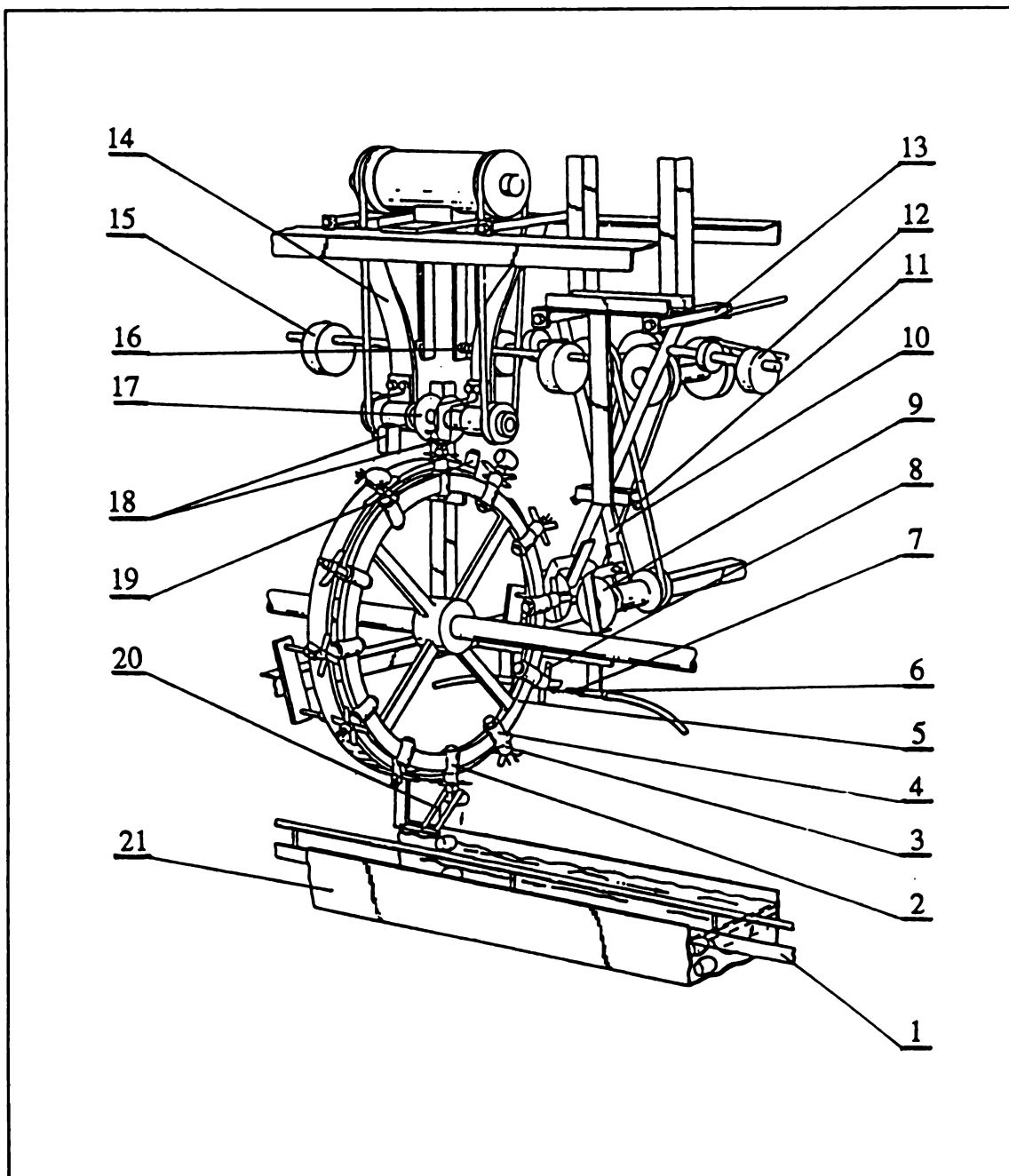
1. Stopper 2. Air Pipe 3. Lever Arm 4. Rod 5. Lever Arm 6. Can 7. Return Spring 8. Disc

Figure 15A The configuration of discharge section of BUYER Machine (1973)

16, (Spring Gully Pickles Pty, Limited, Australia,1980). They have small and simple construction, low but practical automation devices and corresponding transmission and control systems. They are easy to operate and maintain. They have small to medium processing capacity and are inexpensive.

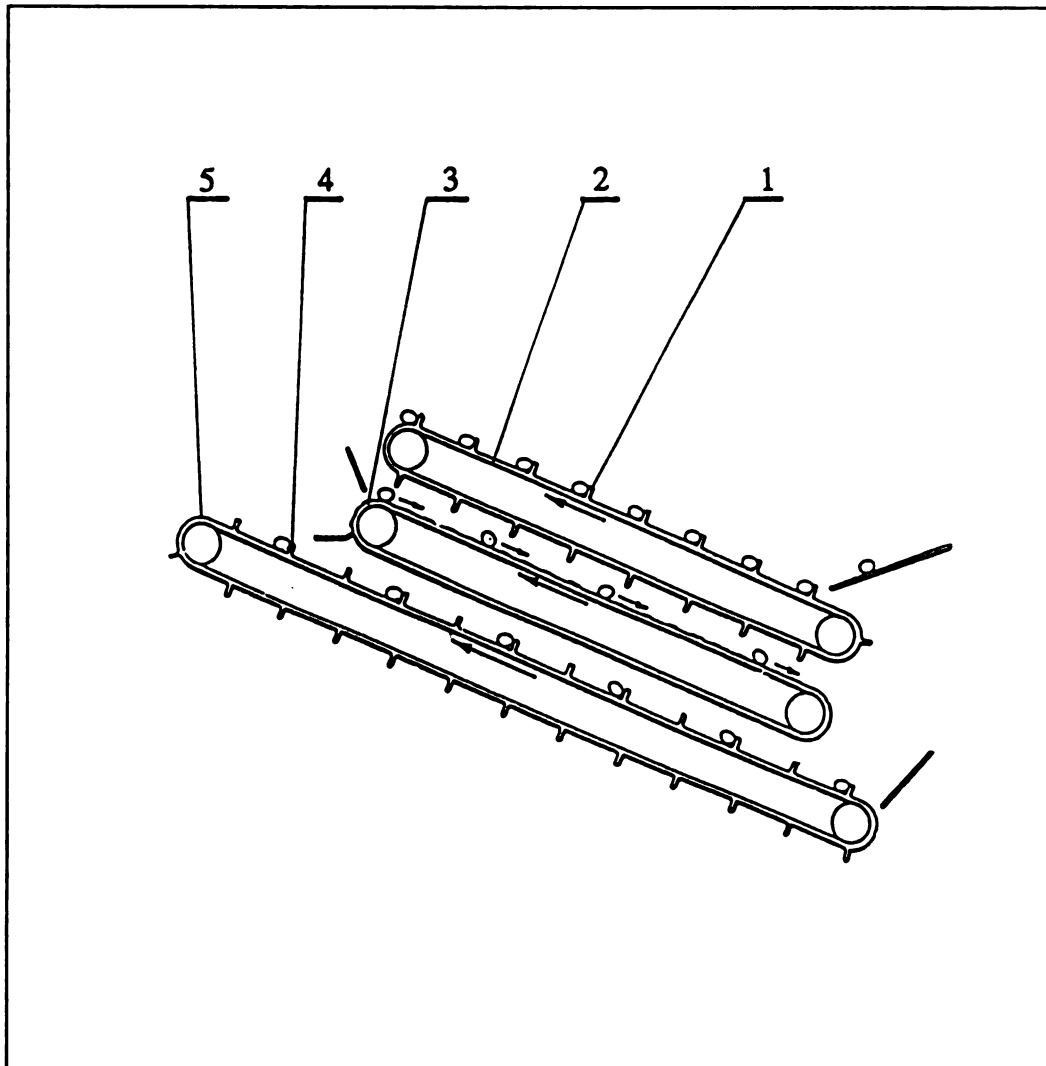
Another complication is that onion peeling is frequently performed together with other agricultural technologies, such as onion harvesting. The machines are not designed specifically for peeling onions, but they do part of the peeling job. They are operated in fields, not in houses, such as, Pat. 4,373,589, Figure 17, *Harvesting Apparatus For Onions*, (Hagiz, 1981). The machine is designed for Sharnoa Ltd., Petach Tikva, Israel to harvest field dried onions. The machine includes efficient cleaning, trimming, sorting and bagging devices. It is even named Harvesting Apparatus and actually about 50% of the cost of the machine is absorbed in equipment to perform the peeling jobs, cleaning, sorting and trimming. The PETRIE Machine, Figure 18, *Onion-Topping Machine* and SCHROEDER Machine, Figure 19, *Onion-Topping Machine* are other examples of onion peeling machines designed to work in fields after onion harvesting.

Another reason for onion machine variety is that even in the same peeling technology, there are several different kinds of machines. They employ different physical principles in design and have different structures and processing procedures. Take for example, Pat. 4,457,224 (Kino, 1982), Figure 3, *Apparatus for Stripping Onion*. This machine employs the principle of vacuum pressure produced as compressed air at a high speed from a nozzle; the onion is discharged from a cylindrical path into



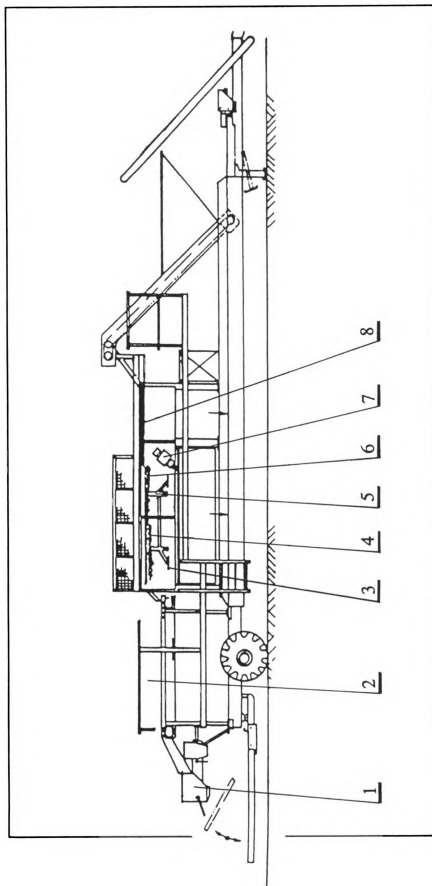
1. Paddle 2. Stem 3. Onion Carrying Device 4. Socket 5. Wheel
 6. Spike 7. Nozzle 8. Finger 9. Slitting knife 10. Swinging Arm
 11. Adjustable Stops 12. Balance Weight 13. Pivot Pin 14. Spring
 Arm 15. Weight 16. Stop 17. Topping and Tailing Knife 18. Feeder
 and Sensing Means 19. Abutment 20. Stripper 21. Trough

Figure 16 U.S. Patent 4,476,778 Onion Peeling (Clyma, 1980)



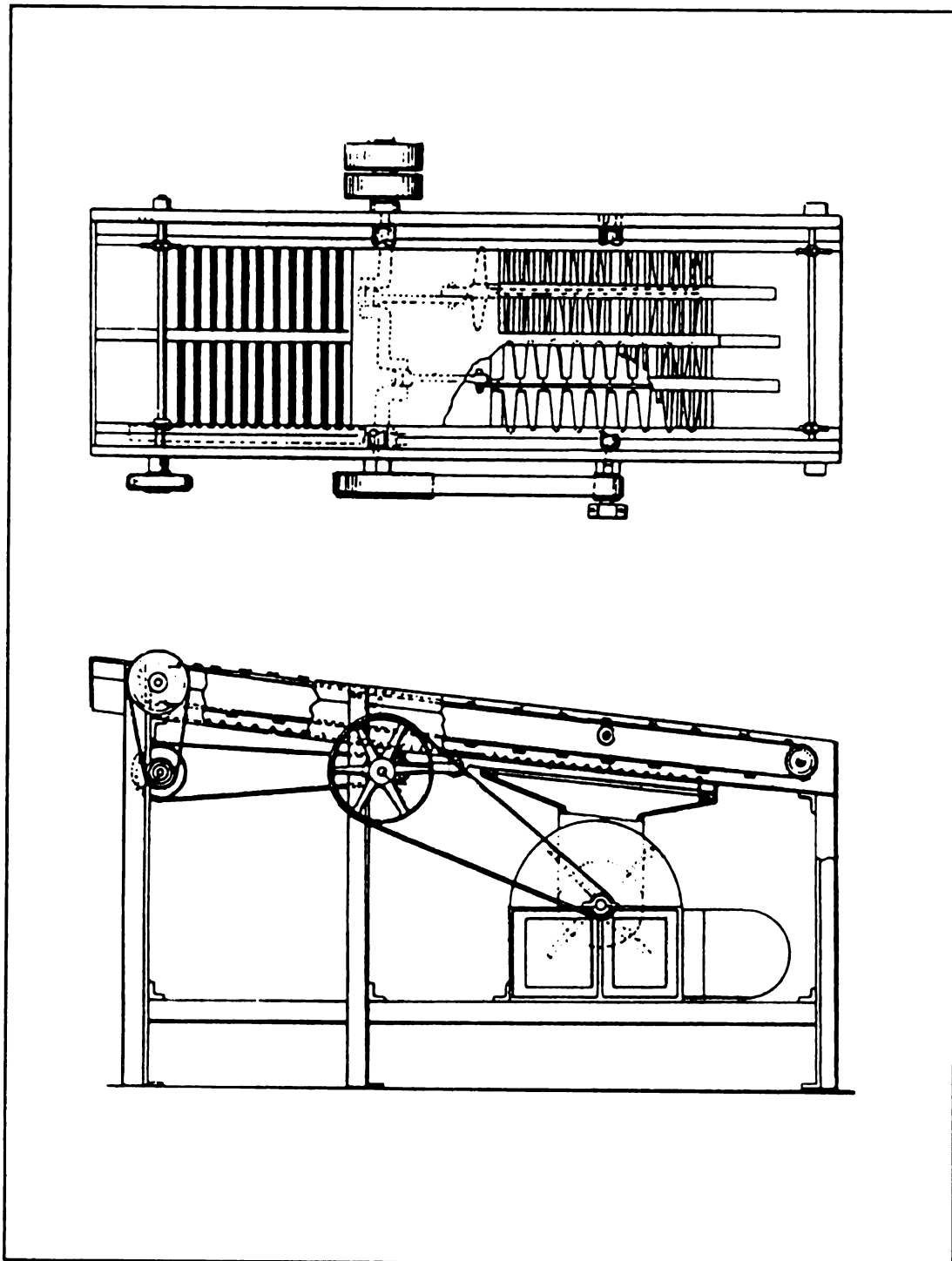
1. Rib 2. Conveyor 3. Smooth Conveyor 4. Slat
5. Further Elevating Conveyor

Figure 16A The Principle of Separator of CLYMAM Machine

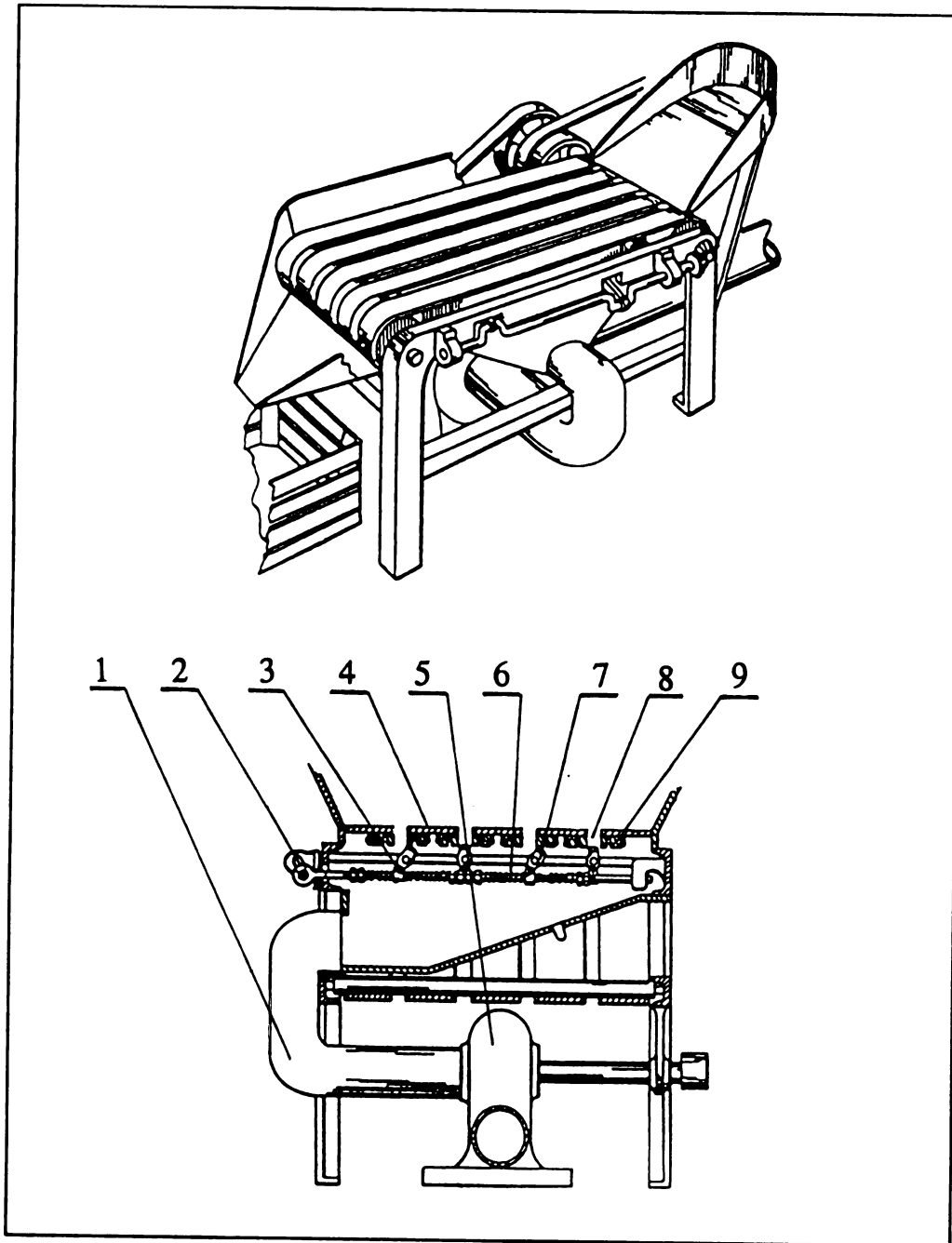


1. Bagging bin 2. Container 3. Rotatable blade assemblies 4. A pair of blades 5. Vertical drive shaft 6. Trimmer 7. Vibratory motion source 8. Pre-cleaner

Figure 17 U.S. Patent 4,373,589 Harvesting Apparatus For Onions (Hagiz, 1981)



**Figure 18 U.S. Patent 926,286, Onion-Topping Machine
(PETRIE, 1908)**

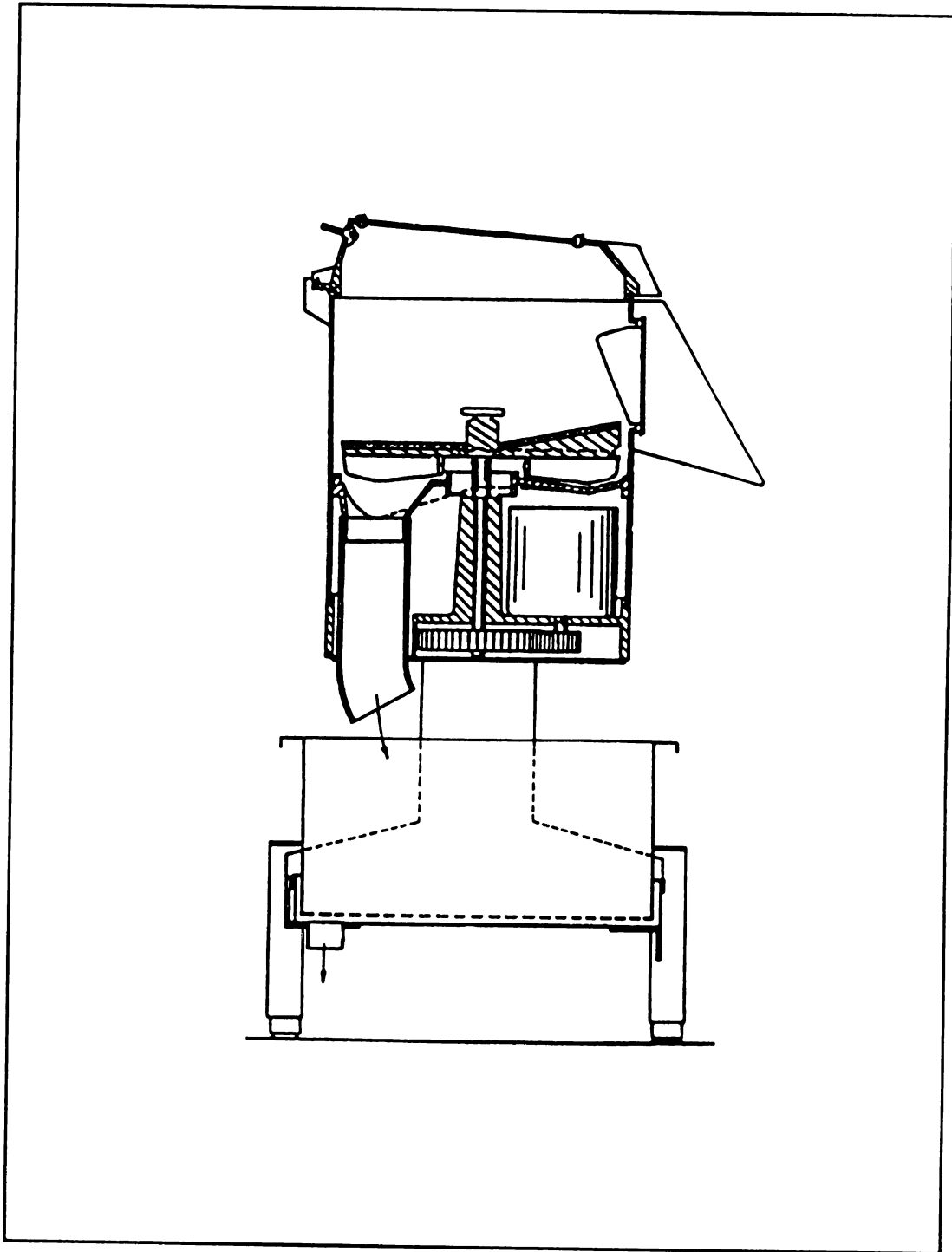


1. Pipe 2. Crank shaft 3. Collar 4. Belts 5. Fan 6. Expansion spring 7. Cutting bar 8. Slots 9. Stationary cutting bar

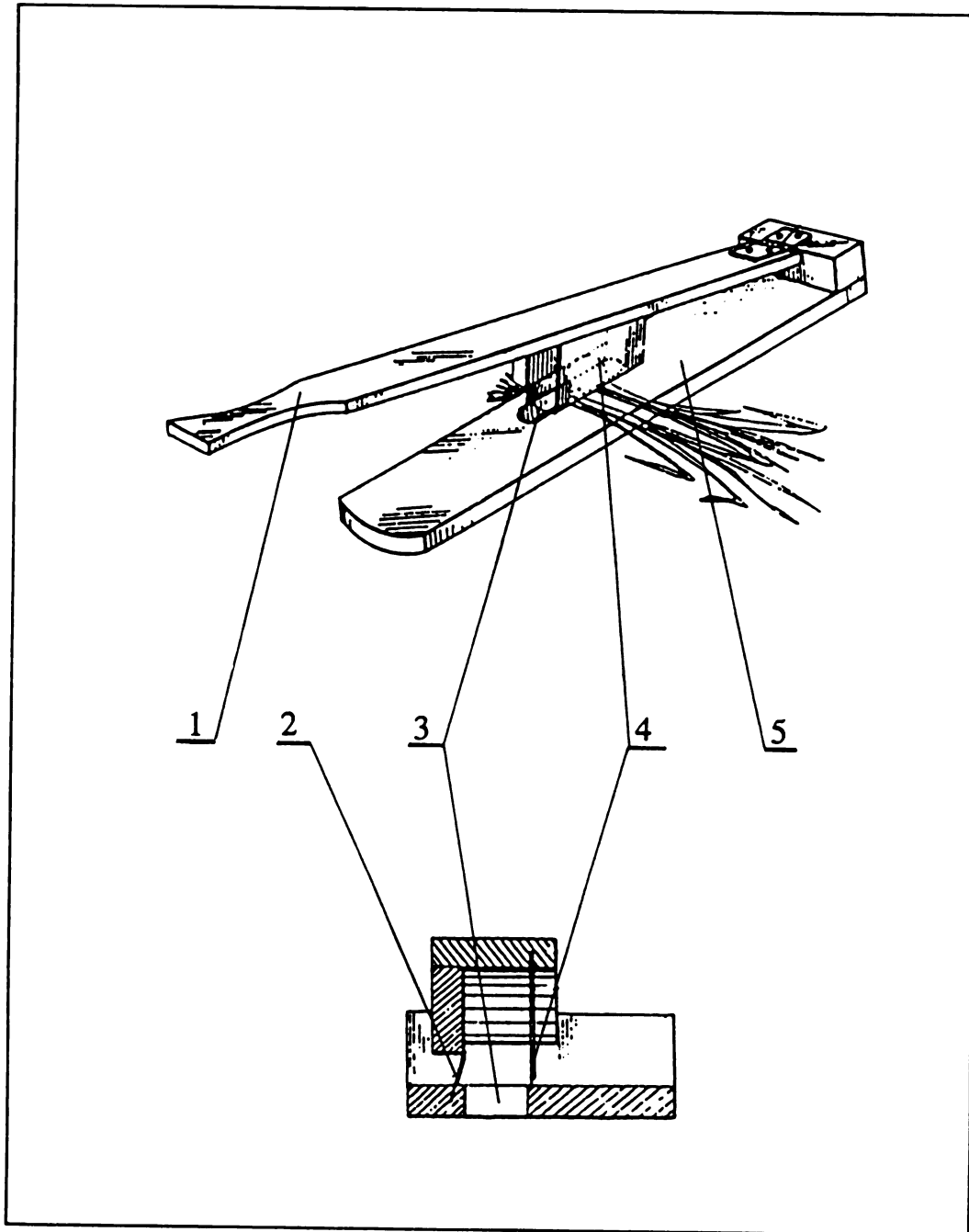
**Figure 19 U.S. Patent 1,379,049 Onion Topping
(Schroeder, 1920)**

a separating chamber facing the path, utilizing the momentum of the onion to realize the peeling function. In this machine, there is no cutting or slitting. The machine has a very different structure and processing procedure from the classical onion peeling machine. A so-called classical onion peeling machine is a machine designed specifically to perform classical peeling technology, which consists of loading, cutting, slitting and peeling processing steps and works in house. Some machines might add orienting as first step and washing as extra step after peeling. In classical processing the onion is transferred by mechanical conveyor or like mechanical devices. Another example which is beyond the classical onion peeling machine is Pat. 4,442,764 (Bos, France, 1982), Figure 20, *Machine for Peeling and Cleaning Foodstuffs, Particularly Vegetables Such As Onions*. This machine uses a clothes washing machine-like principle, a container filled with water, a rotating disc coated with an abrasive layer, and no cutting and slitting in the processing.

Vertically viewing the history of the development of onion peeling machine, we can see that the early-designed machines possessed only one function, trimming or cutting, for instance. Their structures were very simple. And often they were manpower driven or only semi-automated, such as, Pat. 926,286 (Petrie, 1908), Figure 18, *Onion-Topping Machine*. Pat. 1,294,033 (Bizette, 1918), Figure 21, *Onion-Cutter*. And Pat. 1,379,049 (Schroeder, 1921), Figure 19, *Onion Topping Machine*. From the 1930s to about the late 1940s, pockets, conveyors and rotatable cutting knives were employed in machines to increase the processing capacity and efficiency. The representative machines are such as, Pat. 1,995,694 (W. E. Urschel, 1932), Figure 22, *Onion Snipper*. Pat. 2,494,914 (J. R. Urschel,

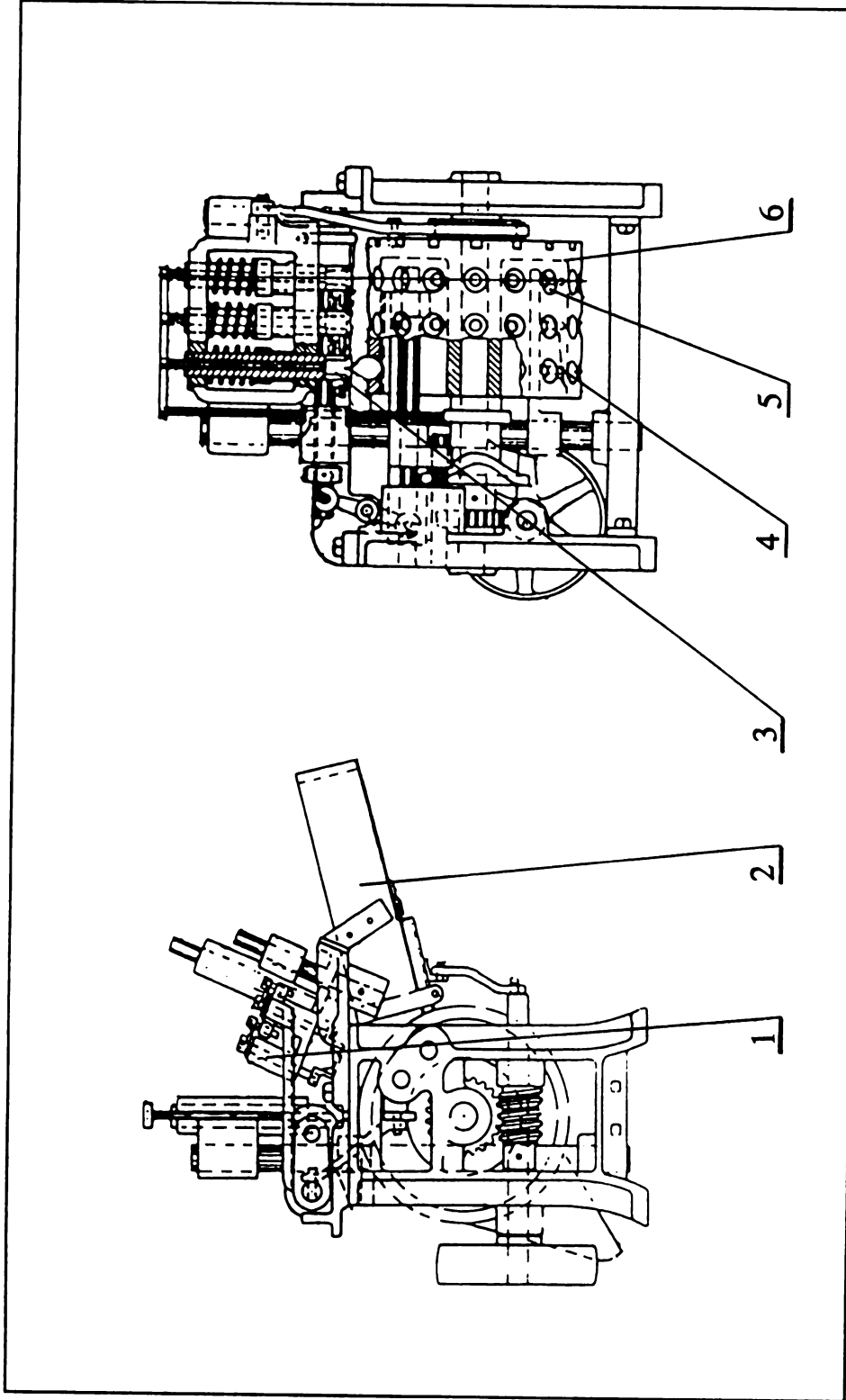


**Figure 20 U.S. Patent 4,442,764 Machine For Peeling And
Cleaning Foodstuffs, Particularly Vegetables Such As Onions
(Bos, 1982)**



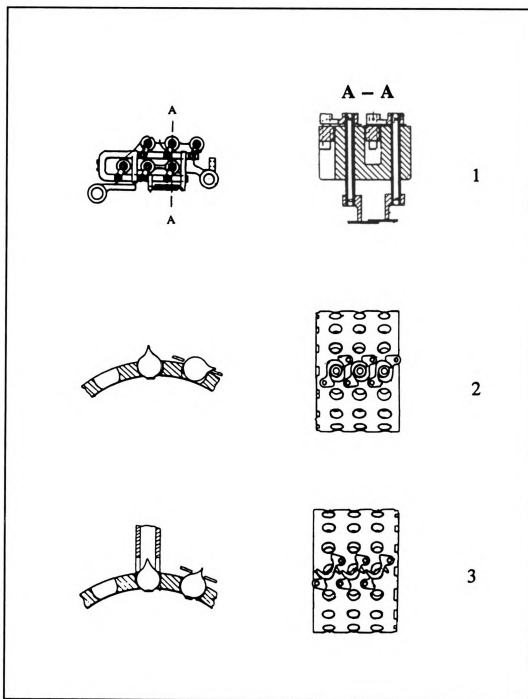
1. Oscillatory Plate 2. Blade 3. Opening 4. Blade 5. Plate

**Figure 21 U.S. Patent 1,294,033, Onion-Cutter
(Bizette, 1918)**



1. finger mechanism 2. feeding hopper 3. reciprocating knives 4. ejector pins 5. Pocket 6. Drum

Figure 22 U.S. Patent 1,995,694 Onion Snipper (W. E. Urschel, 1932)



1. The structure of finger mechanism 2. Finger opening position
3. Finger closed position

Figure 22A The Orienting Mechanism of URSHEL Machine (1932)

1944), Figure 11, *Machine for Clipping Onions and the Like* and Pat. 2,553,519 (Lenz, 1946), *Onion Toper*.

Later on, about in the 1950s, the high pressure fluid jet was employed in onion peeling. This was a very important development. It quickly became a major peeling technique appearing in almost every classical onion peeling machine, such as, Pat. 2,445,881 (Hemmeter, 1945), Figure 23, *Apparatus For Peeling Onions, Including A Conical Jet of Gas*. Pat. 2,602,480 (Taylor, 1948), Figure 4, *Onion Skinning and Slicing Machine*. Pat. 2,766,794 (Odale, 1952), Figure 24, *Method of Removing Outer Skin From Vegetables*. Pat. 2,750,977 (Vella, 1953), Figure 25, *Apparatus For Clipping Tops From Onions*.

From the late 1940s through the 1960s, the onion peeling machine made a great leap forward. Air jet peeling technique, complex orienting assembly, and self-regulating slitting and cutting mechanisms were added in onion peeling machines. In this period, the machine developed into a multi-functional machine system. Many functions, such as, cleaning, orienting, holding, cutting and slicing, as well as peeling, were often included in one machine. And the machines had a higher level of automation. The typical machines are Pat. 2,602,480 (Taylor, 1948), Figure 4, *Onion Skinning and Slicing Machine* (included cutting, slitting, peeling and slicing). Pat. 2,750,977 (Vella, 1953), Figure 25, *Apparatus for Clipping Tops from Onions (included air flow orienting and cutting)*. Pat. 2,961,023 (Boyer, 1958), Figure 12, *Vegetable Trimming Machine* (included holding and cutting). Pat. 3,485,279 (Parsons, 1966), Figure 26, *Treatment For Onions* (included holding, slitting, cutting and peeling). Pat. 3,515,193

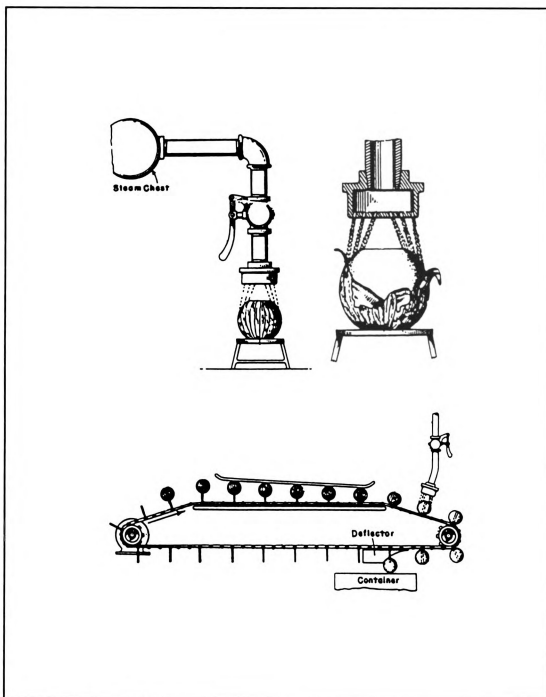


Figure 23 U.S. Patent 2,445,881 Apparatus for Peeling Onions, Including a Conical Jet Gas (Hemmeter, 1945)

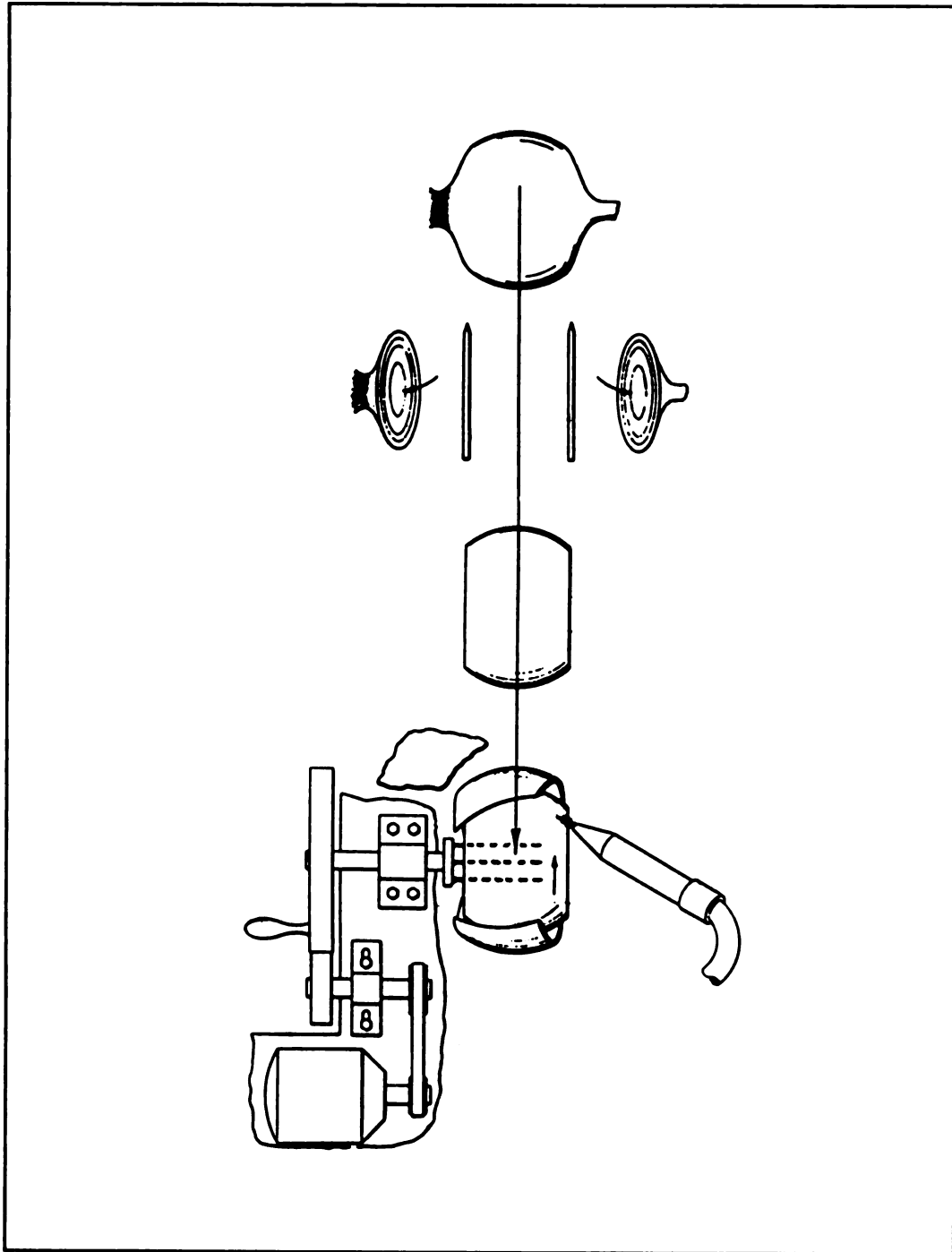
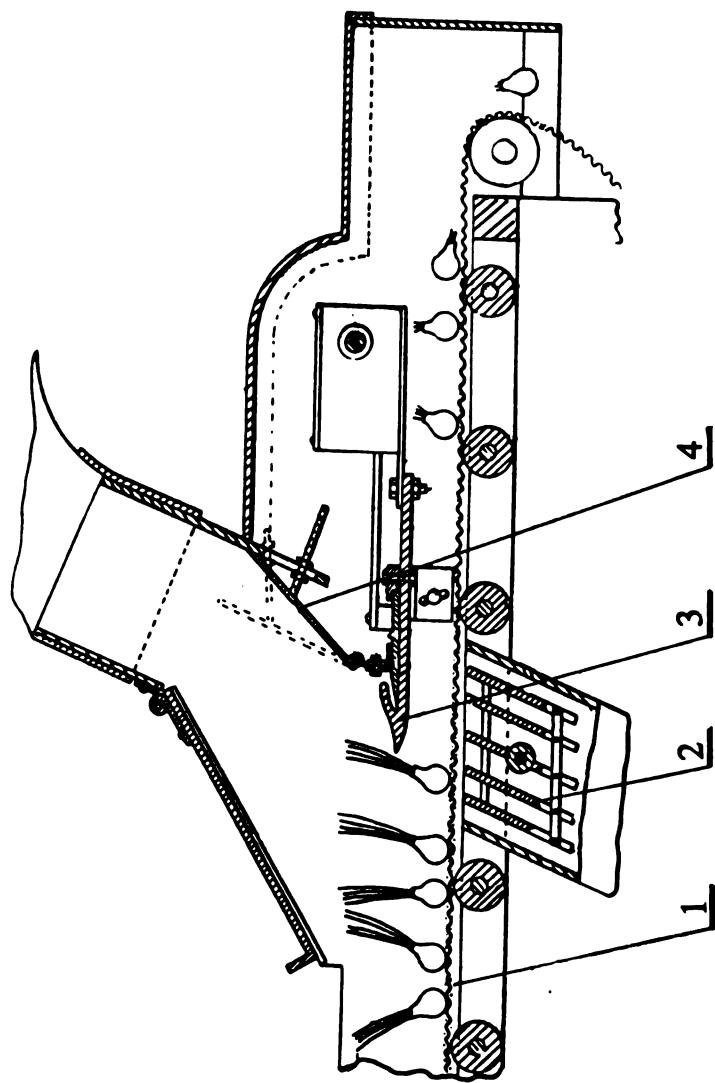
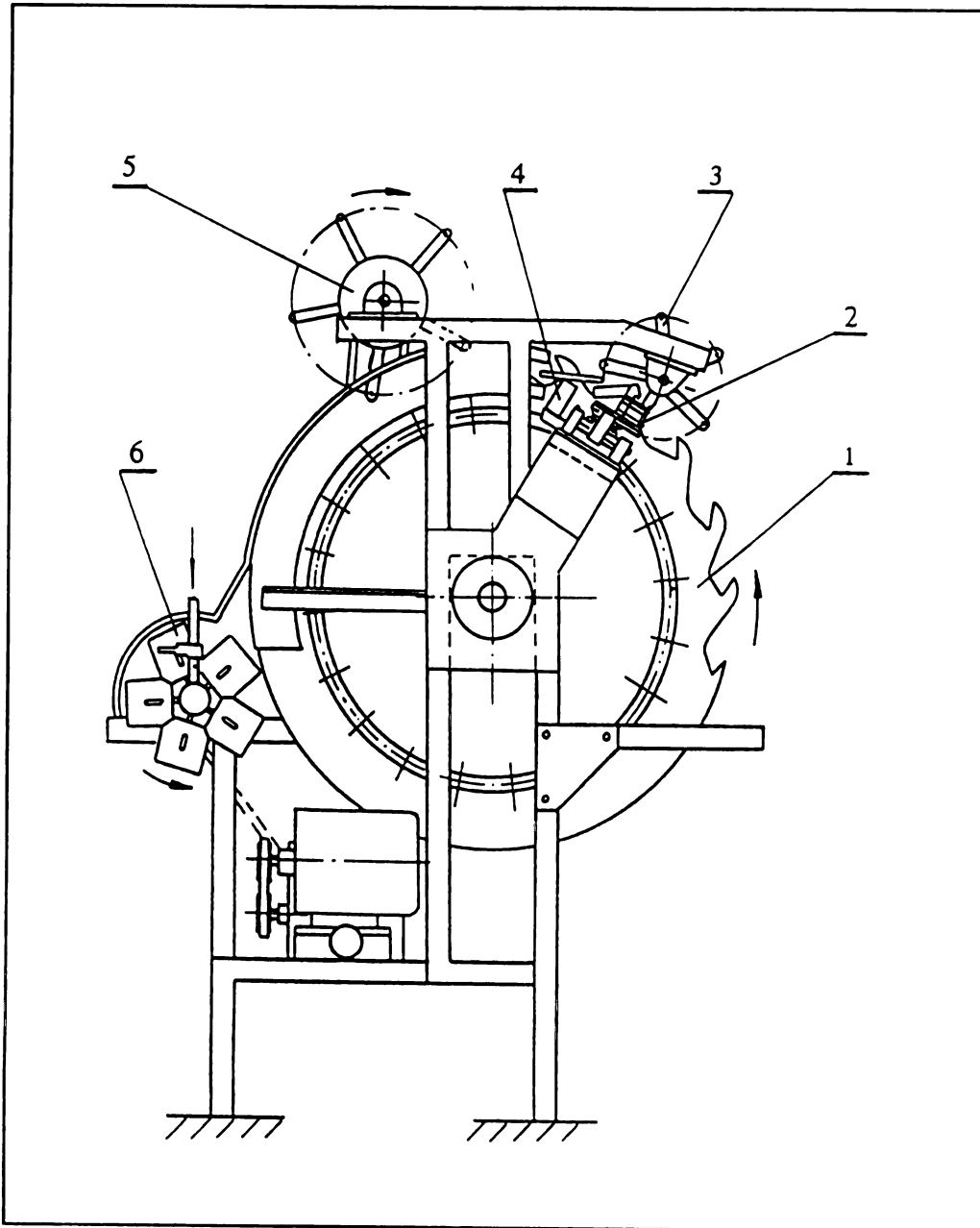


Figure 24 U.S. Patent 2,766,794 Method of Removing Outer Skin From Vegetables (Odale, 1952)



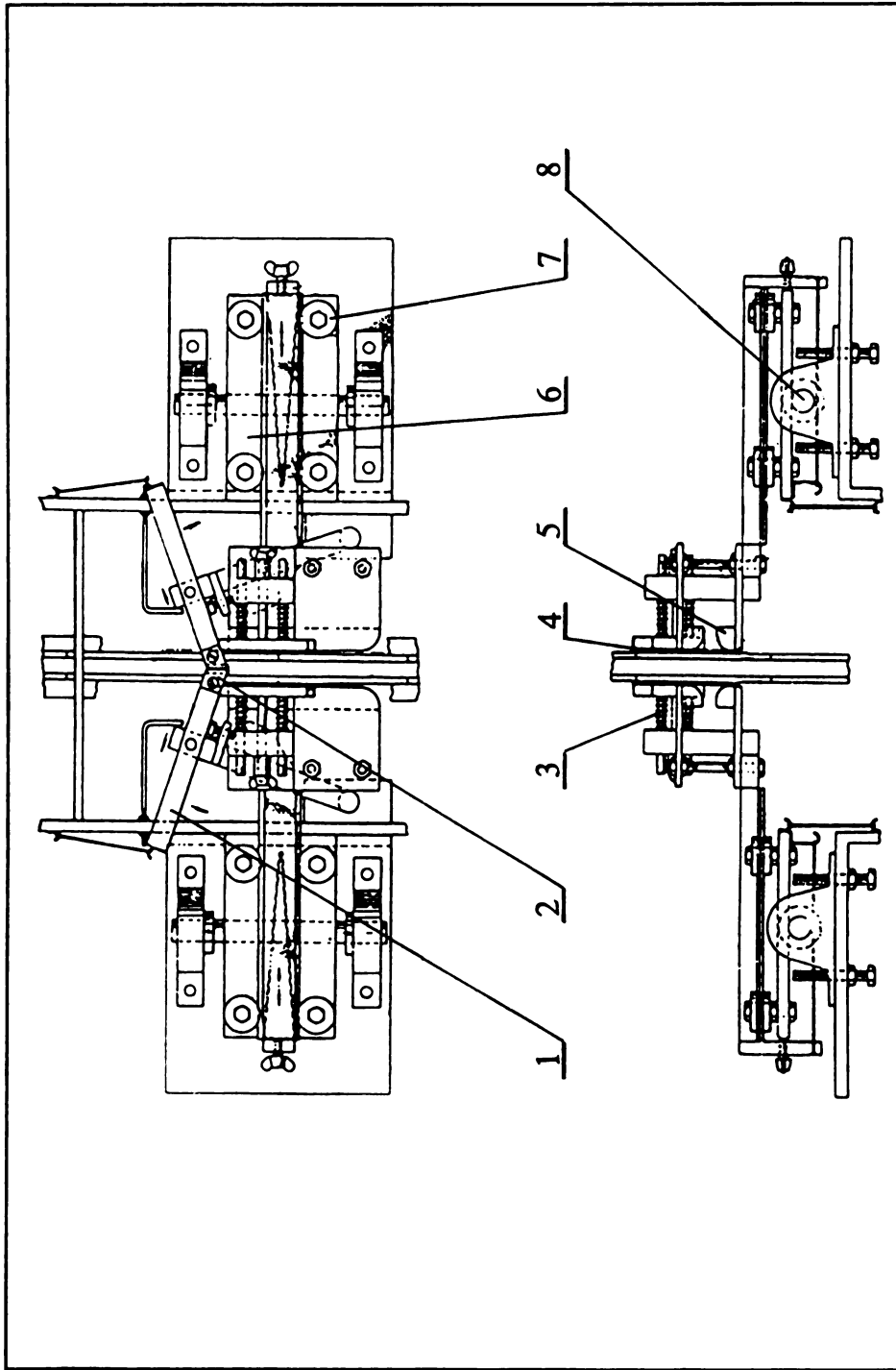
1. Chain conveyor 2. Air outlet tube 3. Cutting blade 4. Baffle plate

Figure 25 U.S. Patent 2,750,977 Apparatus For Clipping Tops From Onions (Vella, 1953)



1. Onion Carrier 2. Topping and Tailing Knives 3. Frictional
Restrain Star Wheel 4. Slitting Knives 5. Ejecting Star
Wheel 6. Air Blast Skinning Apparatus

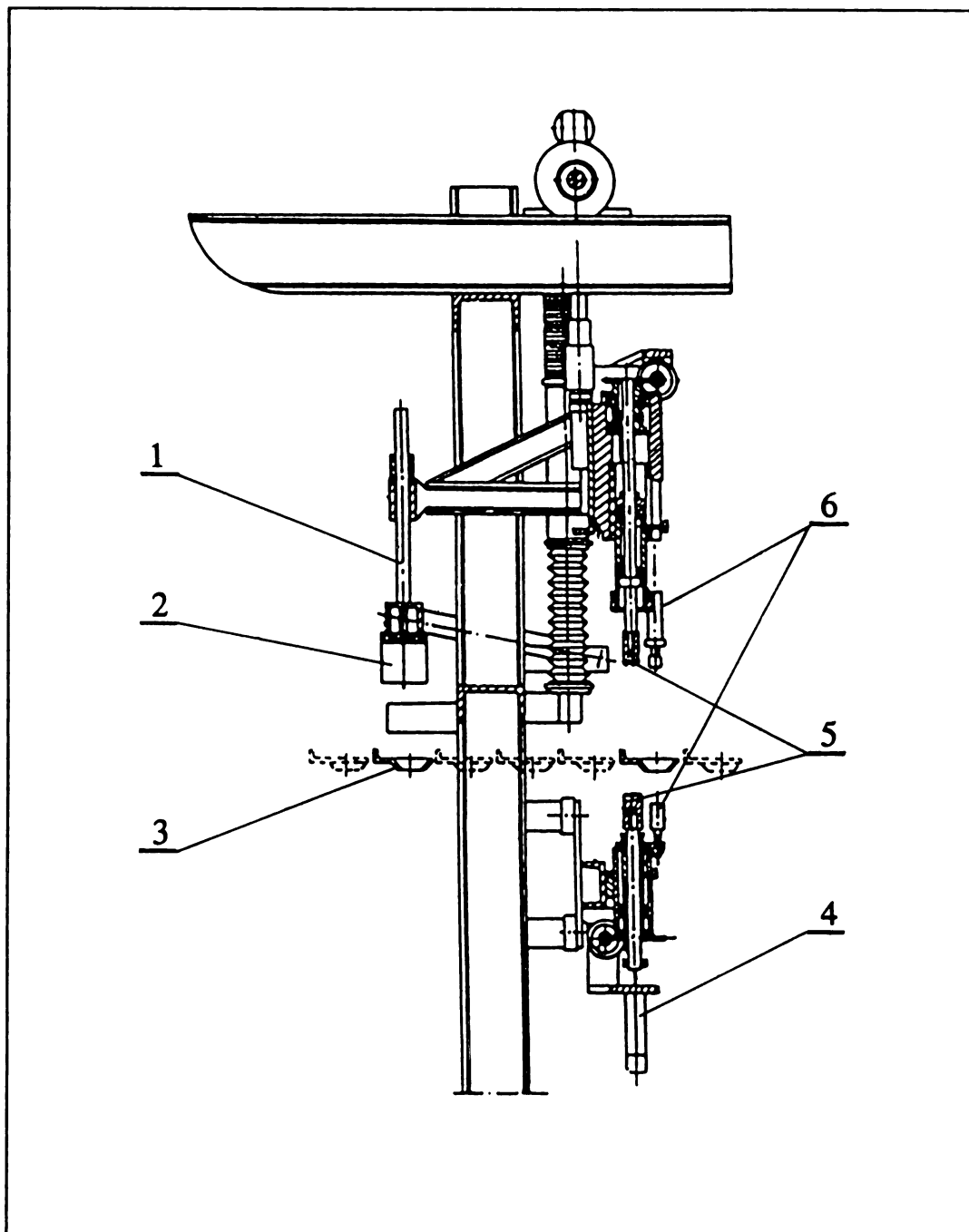
**Figure 26 U.S. Patent 3,485,278 and U.S. Patent 3,485,279
Treatment Of Onions (Parsons, 1966)**



1. Slitting arm 2. Slitting blade 3. Compression spring 4. cutting blade 5. Upper and lower guide blocks 6. Slide bar 7. Roller 8. Spindle
Figure 26A U.S. Patent Cutting and slitting mechanism of PARSONS machine (1966)

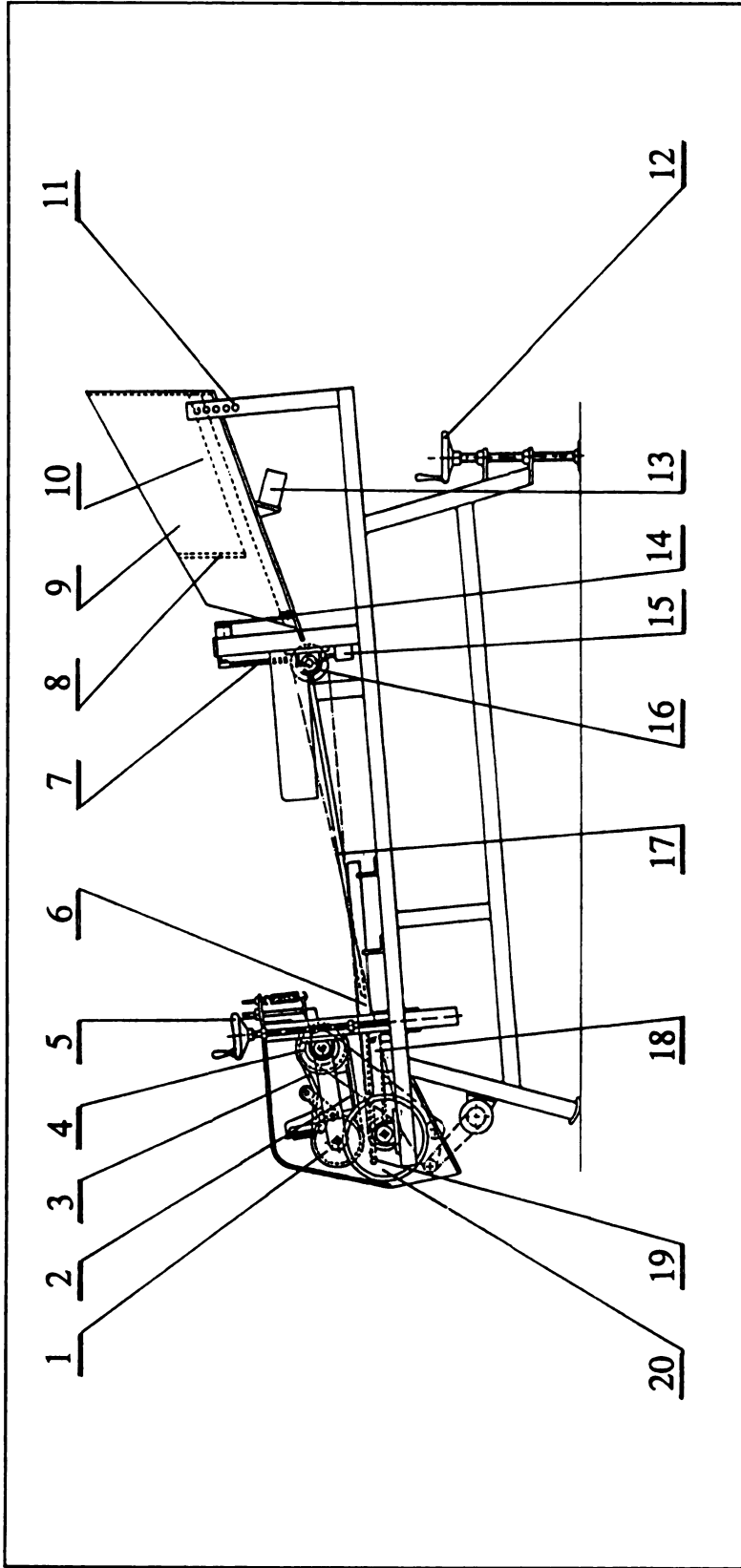
(Aguilar, 1967), *Figure 6, Onion Orienter and Cutter (included orienting, holding and cutting. Pat. 3,623,524 (Buck, 1968), Figure 13, Machine For Preparing Onions (included holding, slitting, cutting and peeling) and so on.* However, in this period, even as the machines' automation level and performing functions were increased, their efficiency and reliability were not satisfactory enough to warrant mass production. For example, the machine system was timed and intermittent. Such as, Pat. 1,995,694, (Urschel, 1932), *Figure 22, Onion Snipper. Pat. 2,602,480, (Taylor, 1948), Figure 4, Onion Skinning and Slicing Machine. Pat. 3,485,279, (Parsons, 1966), Figure 26, Treatment of Onions and Pat. 3,623,524, (Buck, 1971), Figure 13, Machine for Preparing Onions.*

By the 1970s, the machines were built more like industrialized products, in that their layout was more reasonable and compact, they used more interchangeable and standardized components and had higher adaptability. The machine's automation had been further increased. New techniques and new materials were widely adopted, and, also, the type of machine, the machine's capacity and efficiency, as well as its safety were developed to a new level to satisfy all kinds of requirements and situations. The typical works included, Pat. 3,696,848 (Mellon, 1970), *Figure 8, Method and Apparatus For Removing Skin From Onions or Like Vegetables.* This is an embryonic form of modern onion peeling machine. Pat. 3,765,320 (Raay, 1971), *Figure 27, Onion End Cutter*, electronic sensor and pneumatic components used in the machine. Pat. 3,915,083 (Spruijt, 1973), *Figure 28, Apparatus For Automatically Processing Bulbous And Tuberous Plants* is a very large capacity onion peeling machine. It can peel onions



1. Duct 2. Cup-shaped nozzles 3. Cup-shaped opening
4. Pneumatic cylinder 5. Knives 6. Feelers

Figure 27 U.S. Patent 3,765,320 Onion End Cutter (Raay, 1971)



1. Second pulley 2. Pressure block 3. Conveyor rope 4. First pulley 5. Height adjustable shaft 6. V-shape chute 7. Brush 8. Partition 9. Trough 10. Guide means 11. Adjustable supporter 12. Sloping position adjusting mechanism 13. Vibrator 14. Leaf spring 15. Pawl mechanism 16. Speed adjustable feeding blade wheel 17. Feed chute 18. Blade holder 19. Cutting depth limiter 20. End cutting blade

Figure 28 U.S. Patent 3,915,083 Apparatus For Automatically Processing Bulbs And Tuberos Plants (Spruijt, 1973)

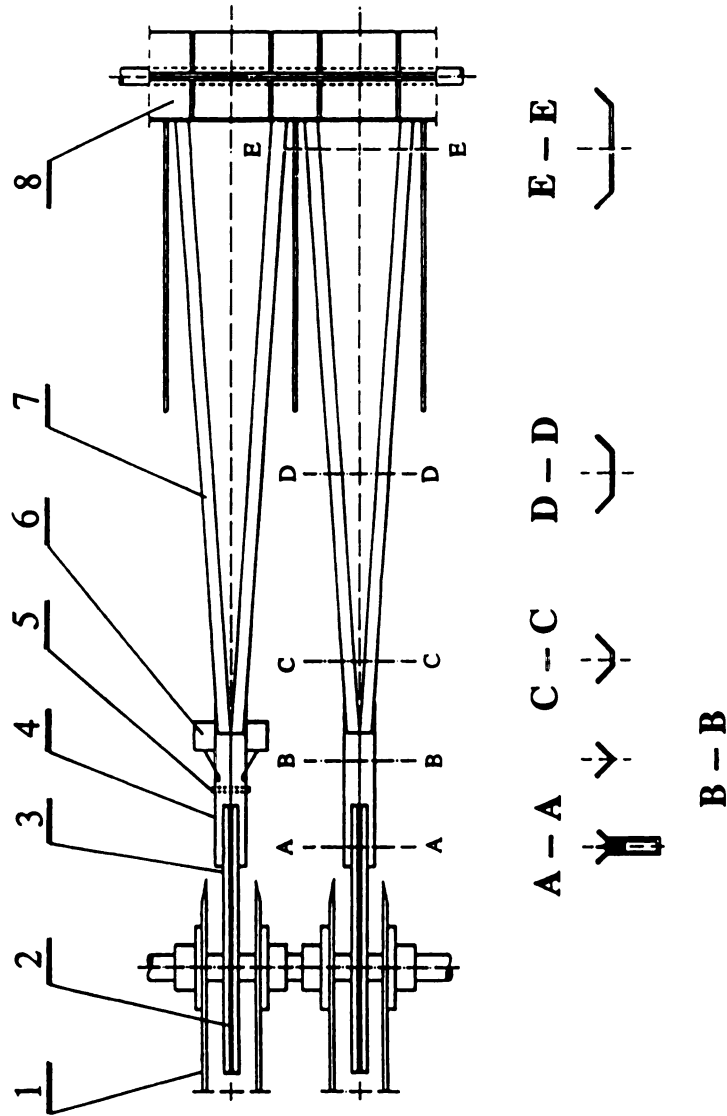
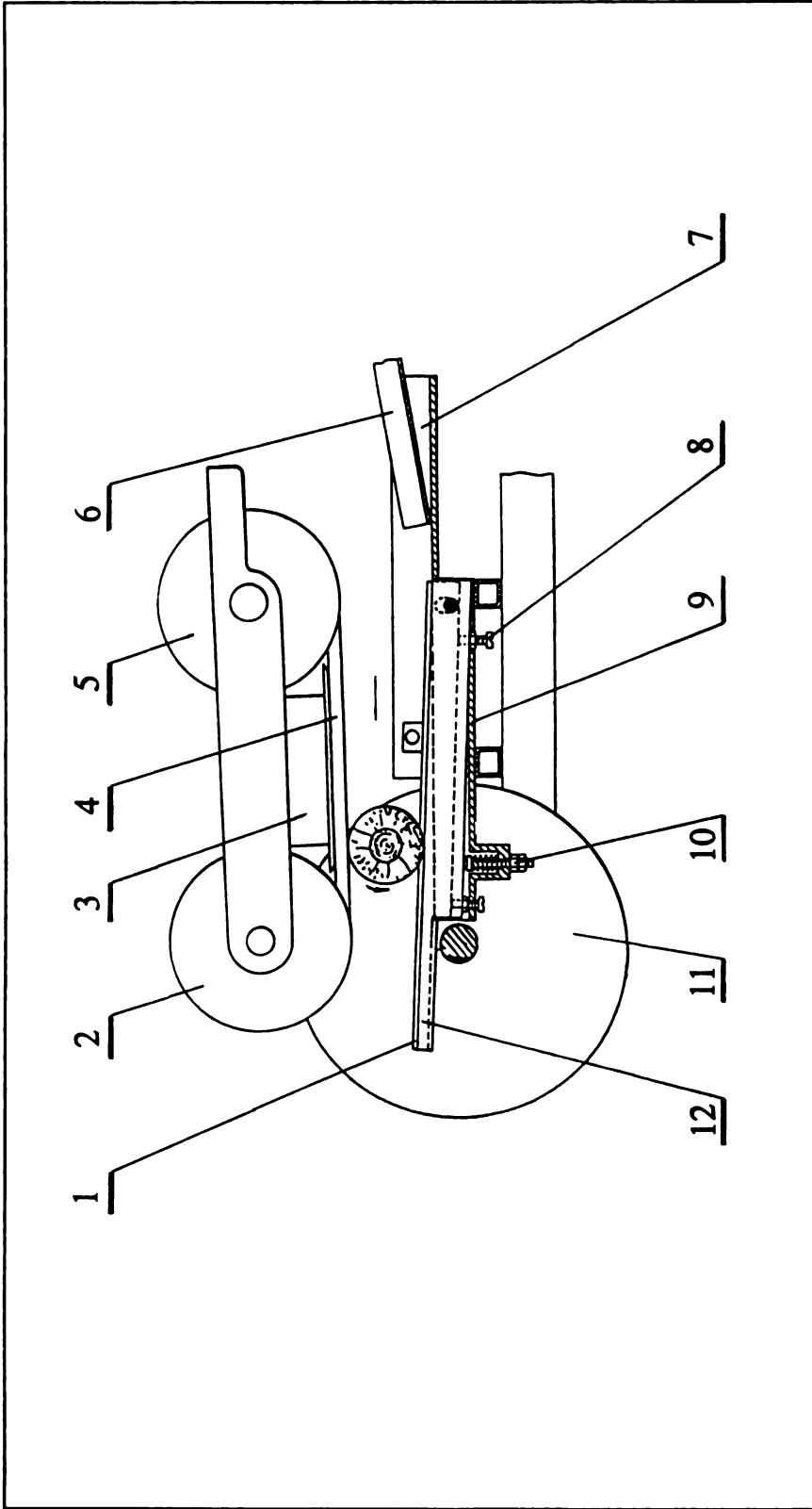


Figure 28A The structure of orienting section of SPRULJT Machine (1973)



1. Notching blade 2. Second pulley 3. Pressure block 4. Conveyor rope 5. First pulley
6. Feed chute 7. V-shape chute 8. Depth adjusting screw 9. Blade holder 10. Notching
blade spring supporter 11. End cutting blade 12. Adjustable cutting depth limiter

Figure 28B The Structure of slitting and cutting section of SPRULJT Machine (1973)

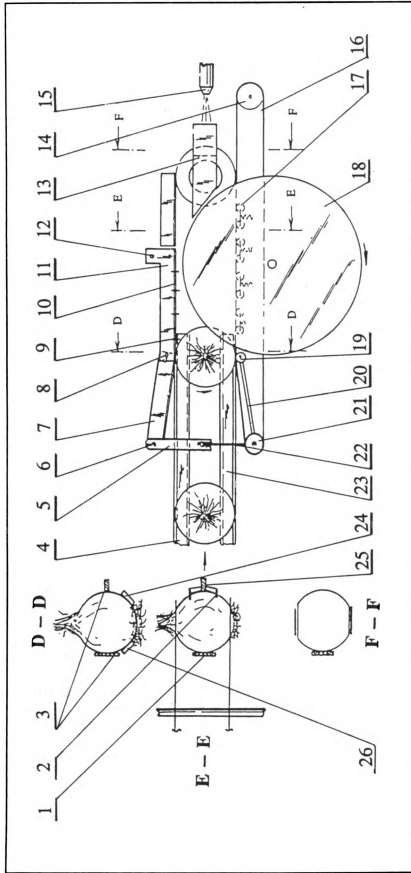
at a rate of 2.5 tons per hour. In this machine, a photoelectric device and electronic sensor control system were considered. Pat. 4,068,011 (Green, 1975), Figure 9, *Method of Peeling Onions by Scalding and Cutting*, is a high automatically operated industrial onion processing machine. It is comprised of a special orienter and separator, and hydraulic components were used and special materials (rubber and plastic) applied in the main components, roller and cam-track. This machine is suitable for large batch processing. Pat. 4,442,764 (Bos, 1982), Figure 20, *Machine For Peeling and Cleaning Foodstuffs, Particularly Vegetables Such As Onions*, is a new type onion peeling machine, whose ideas are completely different from the classical one. The machine is simple and safe, and special material is used for abrasive coating. Pat. 4,481,875 (Toyosato, 1982), Figure 10, *Bulb Peeling Apparatus*. This also is a new type of peeling machine whose principle and structure are much different from existing machines. Its high automatically operated system and reliable structure is suitable for large batch production. Ceramic blades, plastic rollers and holders as well as hydraulic components and systems were applied in the machine.

From this review, we can see that by the 1970s, the classical onion peeling machine had been well developed. Some fundamental mechanisms or structures had been recognized and accepted widely by machine users and designers, such as the endless chain-conveyor, two parallel end-cutting rotatable disc blades, self-regulating adjuster, multiple surface slitting knives and fluid jet peeling. These mechanisms appeared in more and more machines. Researchers' interests have focused on increasing the machine's efficiency, reliability and adaptability and decreased costs, particularly in the industrial onion peeling machine. There are two obstructions to the further

development of the onion peeling machine: loading (orienting), and holding problems. Actually, this is one interrelated problem. Previous practice indicates that if this barrier cannot be broken down, it will be difficult to increase the classical onion peeling machine's efficiency, reliability and adaptability. Before the 1970s, mechanical engineers did some work to improve loading and holding techniques. In holding, for example, spindle-holding, pocket-holding, gripper-holding and belt-hold-down holding, had been tried in a number of machines. The same situation emerged in loading or orienting. Example are vibrator-pocket orienting, Figure 14, (Rood, 1971), friction-pocket orienting, Figure 6, (Aguilar, 1967), air-pressure loading, Fig. 25, (Vella, 1953) and mechanical-finger orienting, Figure 22, (Urschel, 1932), as well as gravity-rolling orienting, Figure 28, (Spruijt, 1973). But, most machines adopted hand loading or orienting. This is because orienting onions to a proper position is a very important processing step in the classical onion peeling machine, and it requires that the orienting mechanisms possess high reliability. Also, obtaining a reliable onion orienting device is not easy either in design or in manufacture. The problem is that onions vary both in their size and shape. It requires a complex mechanism to do the job adequately, and this adds to the machine's cost and reduces its useful life. This is not acceptable to consumers, particularly in case of small or medium processing capacity, such as farm onion peeling machines. Therefore, hand loading or orienting becomes a more and more popular procedure in farm onion peeling machine systems. Nevertheless, in an industrial onion peeling machine system, onion loading or orienting still is a barrier to further increasing processing capacity and efficiency. Solving the bottle-neck problem attracted engineers' interest, and in the

1980s, the developments made in the industrial onion peeling machine mainly centered on solving the orienting problem to increase the peeling efficiency and capacity. The representative arts are, such as, Pat. 4,361,084 (RAATZ, 1981), Figure 29. This machine used rolling orienting and flexible belt holding. Pat. 4,442,764 (Bos, 1982), Figure 20 and Pat. 4,457,224 (Kino, 1982), Figure 3. Pat. 4,470,345 (Miyata, 1983). These three machines eliminated the orienting step by making a complete change in processing technology. Pat. 4,481,875 (Toyosato, 1982), Figure 10. This machine employed rolling and comb-shaped pawls for orienting and holding onions.

How many functions and what functions a machine must perform are mainly determined by application and cost. For example, an onion grower, if he is the supplier to the onion peeling plant or fresh vegetable market needs a machine to perform trimming and cleaning functions only. Commonly, the more functions a machine has, the more the buyer will spend. Loading, that is, putting the onion in the proper place and position for subsequent processes, such as, slitting and cutting, is the first and most important step, particularly in large batch processes. Loading has influenced the whole processing quality and cost. In classical peeling technology, usually there are two kinds of loading methods, machine loading and hand loading. In machine loading, onions are sent by a mechanical conveyor to an orienting mechanism. The principle of gravity, vibration and physical friction are widely applied in the design of such orienting mechanisms. The representative arts are, such as, Pat. 1,995,694, Figure 22, URSCHEL Machine. Pat. 2,750,977, Figure 25, VELL Machine. Pat. 3,515,193, Figure 6, SGUILAR Machine. Pat. 3,764,717, Figure 14, ROOD Machine.



1. Endless conveyor 2. Horizontal continuously extending blade 3. Onion supporting guide 4. Stationary belt 5. Bar 6. Shaft 7. Blade bar 8. Pivotal shaft 9. Notch blade perpendicular to item 8 10. Horizontal continuously extending blade 11. Notch blade bar 12. Pivotal shaft 13. Guide 14. Driven guide roll 15. Blow nozzle 16. Endless conveyor 17. Tensioning elements 18. Topping and tailing knives 19. Guide roll 20. Pantograph arm 21. Guide roll 22. Bar 23. Moving endless belt of the orienting unit 24. Stationary belt 25. Notch blade bar 26. Moving endless belt of the orienting unit

Figure 29 U.S. Patent 4,361,084 Industrial Peeler For Onions Or The Like Bulbous And Tuberous Vegetation (Raatz, 1981)

Pat. 3,915,083, Figure 28, SPRUIJT Machine. Pat. 3,942,428, CLAUSEN Machine. Pat. 4,068,011, Figure 9, GREEN Machine. Pat. 4,361,084, Figure 29, RAATZ Machine and Pat. 4,481,875, Figure 10, TOYOSATO Machine. In hand loading, onions are put by hand to pockets or carriers in a certain position. Such machine has a relatively simple structure and, therefore, lower cost. However, the trade off is higher labor costs. So, usually, only large batch processes adopt machine loading, while small and medium batch processes often use hand loading. Of course, there are some peeling machines which do not need a loading function, such as, Pat. 4,457,224, Figure 3, KINO Machine and Pat. 4,442,764, Figure 20, BOS Machine, since they apply different processing technologies. Similar cases also exist in holding, slitting and cutting functions.

Holding also is a key function, particularly in machines which are equipped with pre-touch self-regulating devices for trimming and slitting, because, they need onions to be held firmly to endure the impact of feelers. In holding, onions are fixed by friction or external force to ensure efficient slitting and cutting. There are a number of holding techniques. Which holding method should be used in the peeling process mainly depends upon the process technology. In earlier times, the ends of onions were removed by manually pushing or pressing the onion against a revolving knife. In this manner, first removing one end and then turning the onion around to remove the other end, the holding was actually done by hand. Since this method is slow, unsatisfactory and dangerous, later on, clamping pin holding (such as Pat. 2,494,914, Figure 11, URSCHER Machine and Pat. 4,476,778, Figure 16, CLYMA Machine. Spike holding, such as, Pat. 2,445,881, Figure 23, HEMMETER Machine. Pat. 2,602,480, Figure 4, TAYLOR

Machine. Pat. 2,766,794, Figure 24, ODALE Machine. Pat. 3,515,193, Figure 6, AGUILAR Machine. Pocket holding, such as, Pat. 2,961,023, Figure 12, BOTER Machine. Pat. 3,485,278, Pat. 3,485,279, Figure 26, PARSONS Machine and Pat. 3,861,295, Figure 15, BOYER Machine. Clamping holding, such as Pat. 3,623,524, Figure 13, BUCK Machine. Pat. 3,606,917, Figure 7, ORLOWSKI Machine and Pat. 3,765,320, Figure 27, RAY Machine. Belt-pocket holding, such as, Pat. 3,696,848, Figure 8, MELLON Machine. Pat. 3,764,717, Figure 14, ROOD Machine. Pat. 3,915,083, Figure 28, SPRUIT Machine and Pat. 4,361,084, Figure 29, RAATZ Machine. Wheel-pocket holding, such as, Pat. 4,068,011, Figure 9, GREEN Machine and Pat. 4,481,875, Figure 10, TOYOSATO Machine) was used in all kinds of classical peeling machines. The difficulty in design of holding mechanism for a classical peeling machine is the interference between the holding mechanism and the multi-slitting knives. The best design of a holding mechanism for multi-slitting peeling in the previous machines are Pat. 3,623,524, Figure 13, BUCK Machine and Pat. 3,696,848, Figure 8, MELLON Machine. In order to accomplish a complete slitting, however, they all added a complex clamping holding mechanism for transferring and turning onions.

Trimming means using knives to cut off the top and root portions of the onions. In the classical onion peeling machine, the function of cutting is performed before slitting and peeling. However, at present, there are some machines whose trimming function is performed after peeling and there is no slitting step in the peeling process. The key in the design of the trimming mechanism is a self-regulating feature. The most important characteristic of the onion peeling machine which distinguishes it from other

machines is that it processes objective products, that is, onions. Onions vary in their size and shape. This is one of the most difficult points in designing an onion peeling machine. How much of the onion will be cut depends upon the space between the two cutting knives. If the space is fixed, the onion will be over-cut, in the case of large-sized onions. This causes higher weight loss. In the case of small-sized onions, the cutting will be insufficient, thereby decreasing the peeling quality. It is need a simple mechanism which can automatically adjust the space by itself to suit all kinds of onions individually. Therefore, whether a machine is supplied with a self-regulating cutting mechanism and how sensitive the mechanism is becomes criteria for evaluating the advantages of the machine. There are several kinds of self-regulating cutting mechanisms. The representative structure is a pre-touch mechanism. The principle is setting two solid feelers on the onion path. On the other end of the feelers is connected a cutting knife assembly. When the onion passes the feelers, the onion itself pushes the feelers away from the central path, depending upon onion's size or shape. The feelers always are kept in a pre-determined position by the tension force of the spring. The sensitivity varies with different designs of the feeler assembly. Examples of the pre-touch cutting mechanism are Pat. 3,485,279, Figure 26, PARSONS Machine. Pat. 3,515,193, Figure 6, AGUILAR Machine. Pat. 3,623,524, Figure 13, BUCK Machine. Pat. 3,764,717, Figure 14, ROOD Machine. Pat. 4,068,011, Figure 9, GREEN Machine and Pat. 4,476,778, Figure 16, CLYMA Machine.

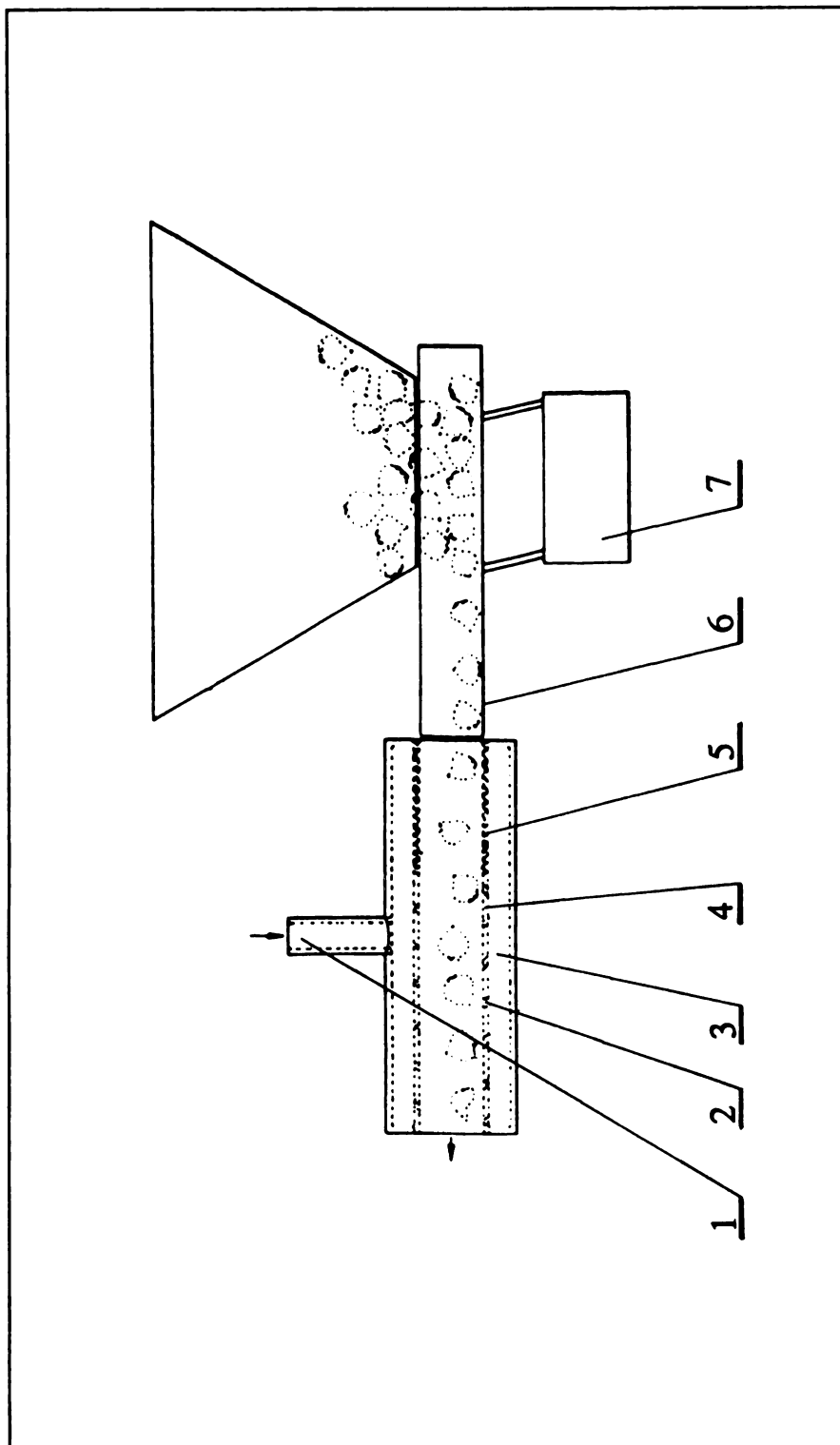
Slitting is using knives to slit the surface of onions. Even though, slitting is only a preparatory step, it seriously influences the quality of subsequent peeling step. In early machines, there is no slitting function

before peeling (such as, Pat. 1,995,694, Figure 22, W. URSCHEL Machine. Pat. 2,494,914, Figure 11, J. URSCHEL Machine. Pat. 2,445,881, Figure 23, HEMMETER Machine. Pat. 2,602,480, Figure 4, TAYLOR Machine. Pat. 2,766,794, Figure 24, ODALE Machine). Later on, a one-slit procedure (equatorial or longitudinal) was considered (in machines such as, Pat. 3,485,279, Figure 26, PARSONS Machine. Pat. 3,623,524, Figure 13, BUCK Machine. Pat. 3,861,295, Figure 15, BOYER Machine. Pat. 3,915,083, Figure 28, SPRUIJT Machine. Later, both equatorial and longitudinal slitting were incorporated, such as, Pat. 3,696,848, Figure 8, MELLON Machine. Pat. 4,068,011, Figure 9, GREEN Machine. Pat. 4,361,084, Figure 29, RAATZ Machine. Now, almost every classical peeling machine includes a slitting function. However, since there are differences in the design of knife's structure, the kinematic locus and the installation of knives, the machines have different efficiencies. An excellent slitting mechanism design is in Pat. 3,696,848, Figure 8, MELLON Machine. In this machine one equatorial and two longitudinal complete slits are made.

Peeling is the target function. There are several ways to peel onions. The most popular way is using high pressure afflux to blast the outer layer of onions. It loosens the outer layers and separates them from the fleshy bulb first, and, then, using special mechanisms such as a roller or tripper, cleans and further strips the loosened skin from fleshy bulb. Air and water are a common medium. Such as, Pat. 2,445,881, Figure 23, HEMOMETER Machine. Pat. 2,766,794, Figure 24, ORALE Machine. Pat. 3,623,524, Figure 13, BUCK Machine. Pat. 3,606,917, Figure 7, ORLOWSKI Machine, Pat. 3,696,848, Figure 8, MELLON Machine. Pat.

4,068,011, Figure 9, GREEN Machine. Pat. 4,476,778, Figure 16, CLYMA Machine and Pat. 4,481,875, Figure 10, TOYOSATO Machine all are typical Air-roller peeling machines. There are other peeling techniques, such as using whirling belt or straps (in such machines as Pat. 2,602,480, Figure 4, TAYLOR Machine. Drum peeling, Pat. 3,485,279, Figure 26, PARSONS Machine. Pat. 3,543,824, Figure 30, PARSONS Machine. Pat. 3,724,362, Figure 5, PARSONS Machine (1970). Pat. 3,861,295, Figure 15, BOYER Machine. Pat. 4,457,224, Figure 3, KINO Machine and Pat. 4,442,764, Figure 20, BOS Machine).

Peeling efficiency is an important criterion to appraise peeling assemblies. Peeling efficiency is directly related to the fluid pressure, the nozzle installation and their shape as well as the distance between nozzles and onions. In 1945, Hemometer introduced a conical, diverging, hollow air jet through a nozzle to loosen the onion skin individually in his Patent 2,445,881, Figure 23. This is an early example of using pressurized fluid to peel the onion skin, but its low efficiency will not serve the needs of large batch processes. In 1948, Taylor designed a interesting peeling mechanism, Figure 4, which consisted of two peeling stations. In the first station, onions were held by a revolving spindle, the peeling functioned by the combined action of a set of flexible straps which are whirled at high speed in contact with the skin, and two steam jets assist in the removal of the skin. The second peeling station repeats the same work done by the first station. In every functioning time the conveyor is paused. In modern mass production, this kind of situation (two peeling stations and one paused conveyor) probably would not be allowed. The problem in the design is the installation of the two steam jets. In 1952, Odale introduced an efficient



1. Compressed air inlet 2. Opening 3. Manifold 4. Tube 5. Roughened part
6. V-shaped section trough 7. Vibrator

Figure 30 U.S. Patent 3,543,824 Treatment Of Fruit And Vegetable Crops (Parsons, 1968)

peeling way, Figure 24, in which a jet is directed against one of the cut end surfaces at its outer layer as the onion is being rotated. Obviously, air jets installed in this way make the peeling efficiency much higher than in the Taylor Machine discussed above. Later, in 1968, Buck developed the idea, Figure 13, of installing two air jets on both sides of the onion, directly against the slits. This design is much better than any previous work. However, the shortcoming is still that there is a distance between the air jet and the onions, and probably this kind of installation is suitable only in an intermittent peeling system. In 1970, Mellon designed a more effective peeling assembly, Figure 8. He installed two sets of jet nozzles on the onion path. One set has two jet nozzles oppositely spaced against the onion cut end surfaces and initially lie on the path of an advancing onion and are displaced from the path when engaged by the onion. The second set of jet nozzles is placed to strike the longitudinal cuts in the onion skin. The advantage of the design is that the nozzles are very close to the slits, so they more effectively use the air force. The disadvantage is that since there are a distance and a period of time between slitting and peeling. The distance causes the machine to run longer, and the time allows the onion skin to shrink.

Summarizing the machine review, we can see that the onion peeling machine has been developed keeping in mind the human demands and the onions' characteristics (which vary with their shape, size and variety) as well as their products, processing batch size, and the working environment. These machines can be grouped into two categories generally, industrial onion peeling machines and farm onion peeling machines. Both of them have valuable applications. In the case of farm onion peeling machines,

they run in the environment of fields or barns; the operators are farmers or seasonal farm workers; and the machine owner usually is a farmer, which requires that the machine be (1) inexpensive both in capital investment and running costs; (2) simple and durable in construction and operation, respectively; (3) small in size and multi-function; (4) and high in processing quality and small or medium capacity.

In addition, in each category there are two types of onion peeling machines, classical onion peeling machines and special onion peeling machines. Each machine employs different peeling technologies. The classical machine is specifically designed for performing classical processing technology and working in house, which cuts onion's top and root portion first, then slits and peels it. Besides this technology there are other physical ways of using the machine to peel onions, all belonging to special peeling technologies.

Moreover, it is known from the review that the holding mechanism, self-regulating cutting feature, multi-slitting knife assembly, air jet installation, general machine layout and continuous operation feature as well as power, convey and control system are all important aspects in evaluating a classical onion peeling machine.

Furthermore, it is understood that the onion peeling machine developed from a manpower-driven or semi-automated process to high automation; from a single function to multi-function; from a purely mechanical system to electronic control and hydraulic power drive system, and that the improvements always have been centered on increasing efficiency, adaptability, reliability and decreasing costs.

Finally, it is known that it is not enough merely through qualitative analysis to evaluate a new type of onion peeling machine. The machine capacity, peeling efficiency and processing weight loss also are important criteria for evaluating the performance of an onion machine peeling system.

However, these belong to a quantitative analysis which needs a statistical experiment and response analysis. Quantitative analysis will be presented in Chapter IV.

CHAPTER III

DESCRIPTION OF THE MSU ONION PEELING MACHINE

3.1 Introduction

The onion peeling machine described here was originally conceptualized by Dr. Ajit K. Srivastava and fabricated in the agricultural engineering department at Michigan State University in 1990. It was designed for a Michigan onion grower to peel pungent Michigan onions for use as the soup ingredient by a canning company. The process which is performed in an onion peeling plant is shown in Figure 31 and the schematic of the peeling machine is shown in Figure 32.

According to the initial proposal, the onion peeling machine should be able to handle smaller Michigan onions with a 500 kg/h peeling capacity and minimum peeling waste. The machine should be designed for farm level use, i.e., it must be simple, durable, and require as little maintenance as possible. It is also required that the machine use as many "off-the-shelf" parts as possible so that parts availability would not be a problem.

This chapter evaluates the MSU Machine qualitatively. It consists of two parts, the processing technology description and the construction evaluation. In the first part of the chapter, the focus is on the introduction

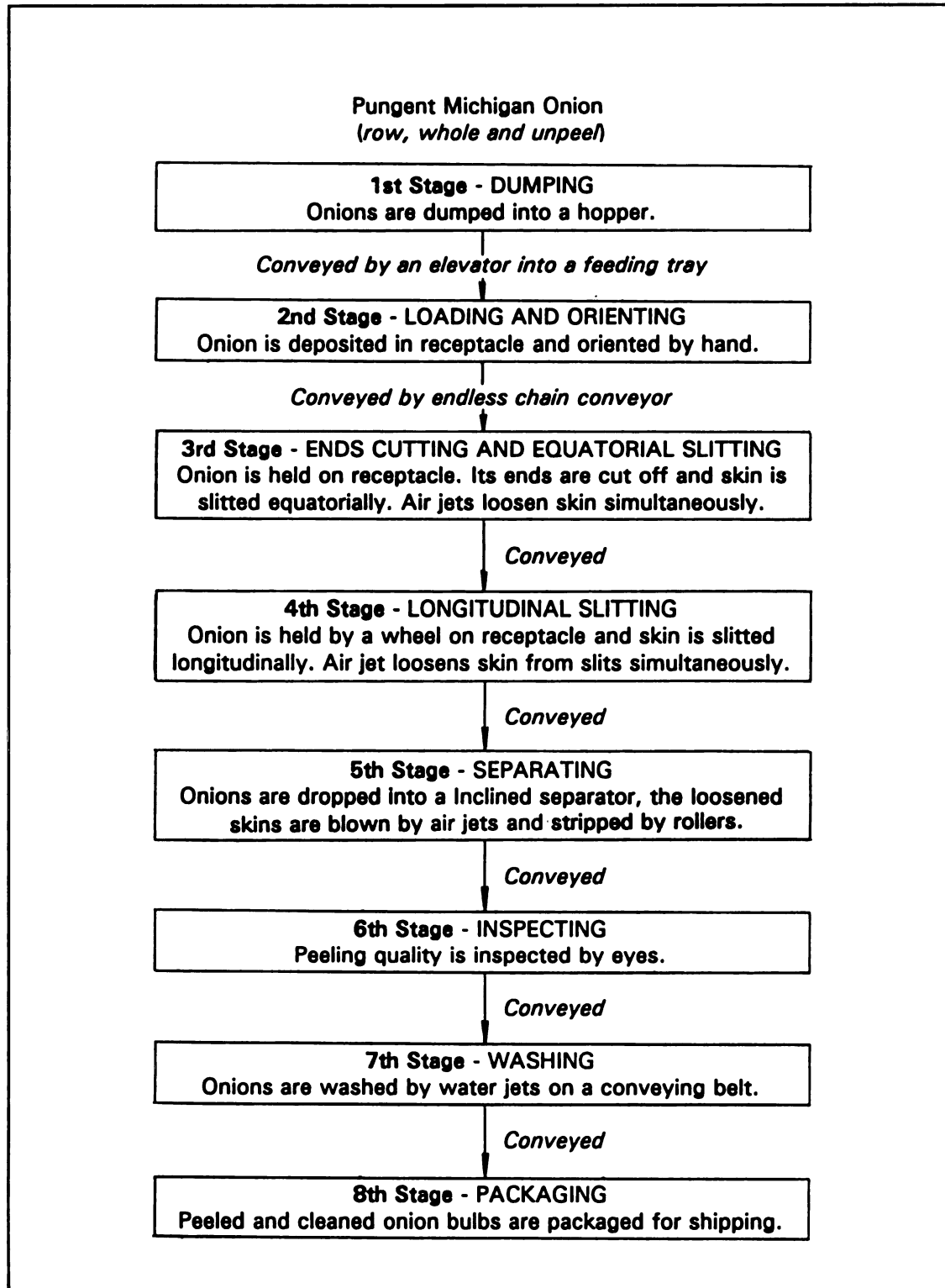
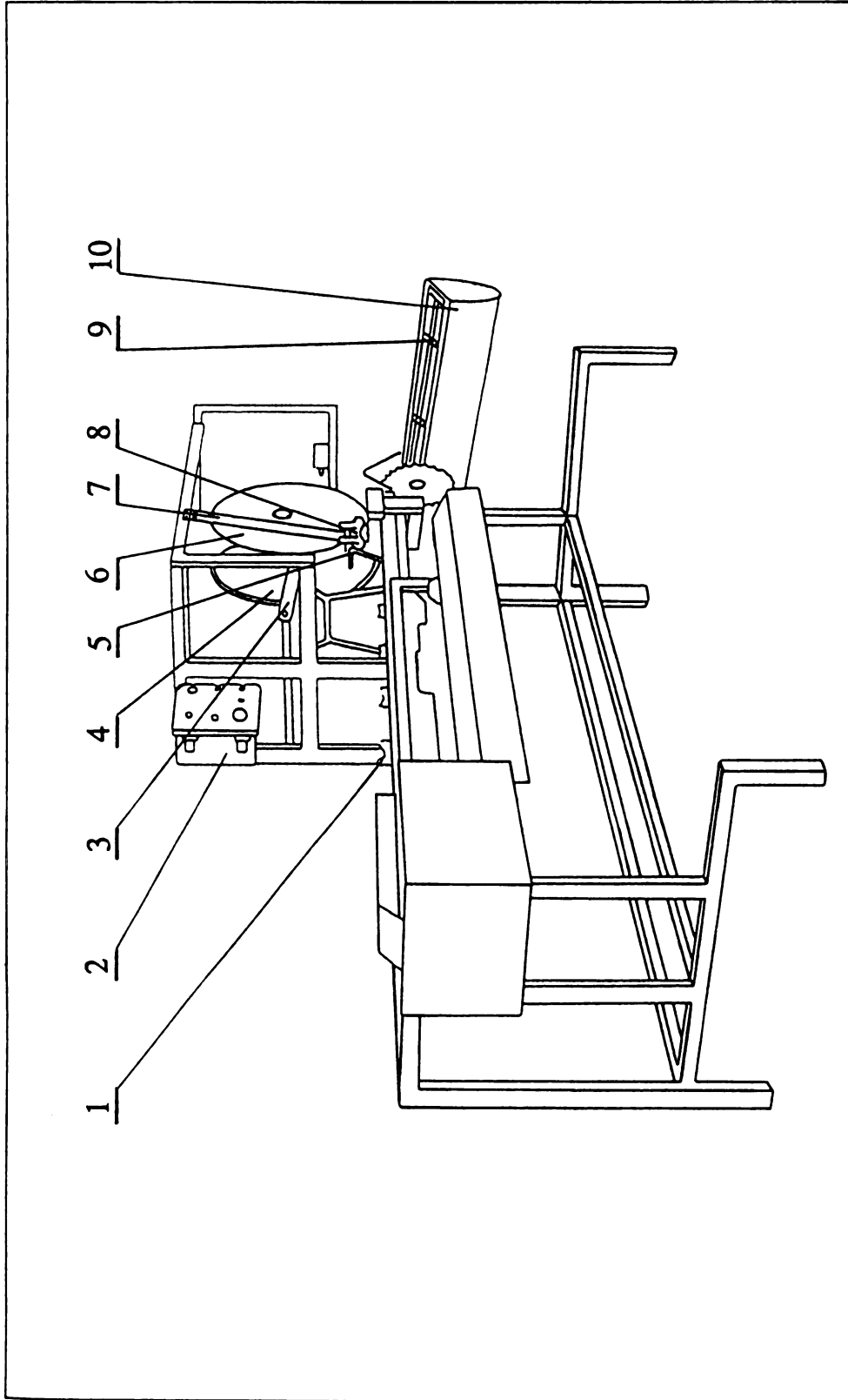


Figure 31 A flow sheet of the technological process performed by MSU Machine during the onion peeling operation



1. V-shaped receptacle 2. Control box 3. Hold-down wheel suspension 4. Ends cutting and equatorial slitting hold-down wheels 5. Self-regulating guide support 6. Longitudinal slitting hold-down wheel 7. Ends cutting knife assembly suspension 8. Cutting knife hydraulic motor 9. Air jet nozzle 10. Separator

Figure 32 A schematic general side view of the MSU onion peeling machine

and discussion of the technological and processing requirements designed for the MSU Machine to produce acceptable onion products efficiently and economically. The second part is devoted to the description of functional components and their distinctive features and effectiveness.

3.2 The Processing Technology of The MSU Machine

The functional processes performed by the MSU Machine in a continuous operation flow include loading, ends-cutting, equatorial slitting, longitudinal slitting and separating. In the processing procedure, there is no chemical or physical damage to onion products. The technological process which consists of eight stages, is briefly shown in Figure 31. The following is a detailed description of the processing technology.

The first two stages were designed to feed onions properly into the machine. The key points in these stages are the loading and orienting quality. Improper loading or insufficient orienting will cause wrong cutting and slitting, consequently, decreasing the peeling quality. However, slow feeding will decrease production. Thus, both factors influence the economic benefits. Also, in view of peeling capacity, annual production quantity, and the budget of capital investment which have been proposed initially, a simple, low cost and reliable feeding way is desired. For this reason, the MSU Machine adopts a lower cost and higher reliable hand-loading and orienting means.

In processing, preliminarily cleaned and graded raw, whole and unpeeled onions are dumped into a hopper. An inclined elevator with

paddled belt is inserted into the hopper, it can be operated easily by hand feeder to convey onions into a feeding tray. The tray is located in front of the operator for conveniently loading and orienting onions onto receptacles.

In the Second Stage, the onions need to be deposited individually into receptacles and positioned to lie transverse to the direction of travel. The onions are loaded and oriented by hand in V-shaped notch receptacles which are fixed with the links of a chain.

In the Third Stage, the technological requirements are to cut off the onion's top and root portions (including the tough core material) properly and to make an equatorial slit on the onion's outer-layer to promote easy removal of the skin from the onion. The technique that the MSU Machine needs to apply to accomplish the technological requirements in this processing stage is mainly determined by the onion's physical and chemical characteristics.

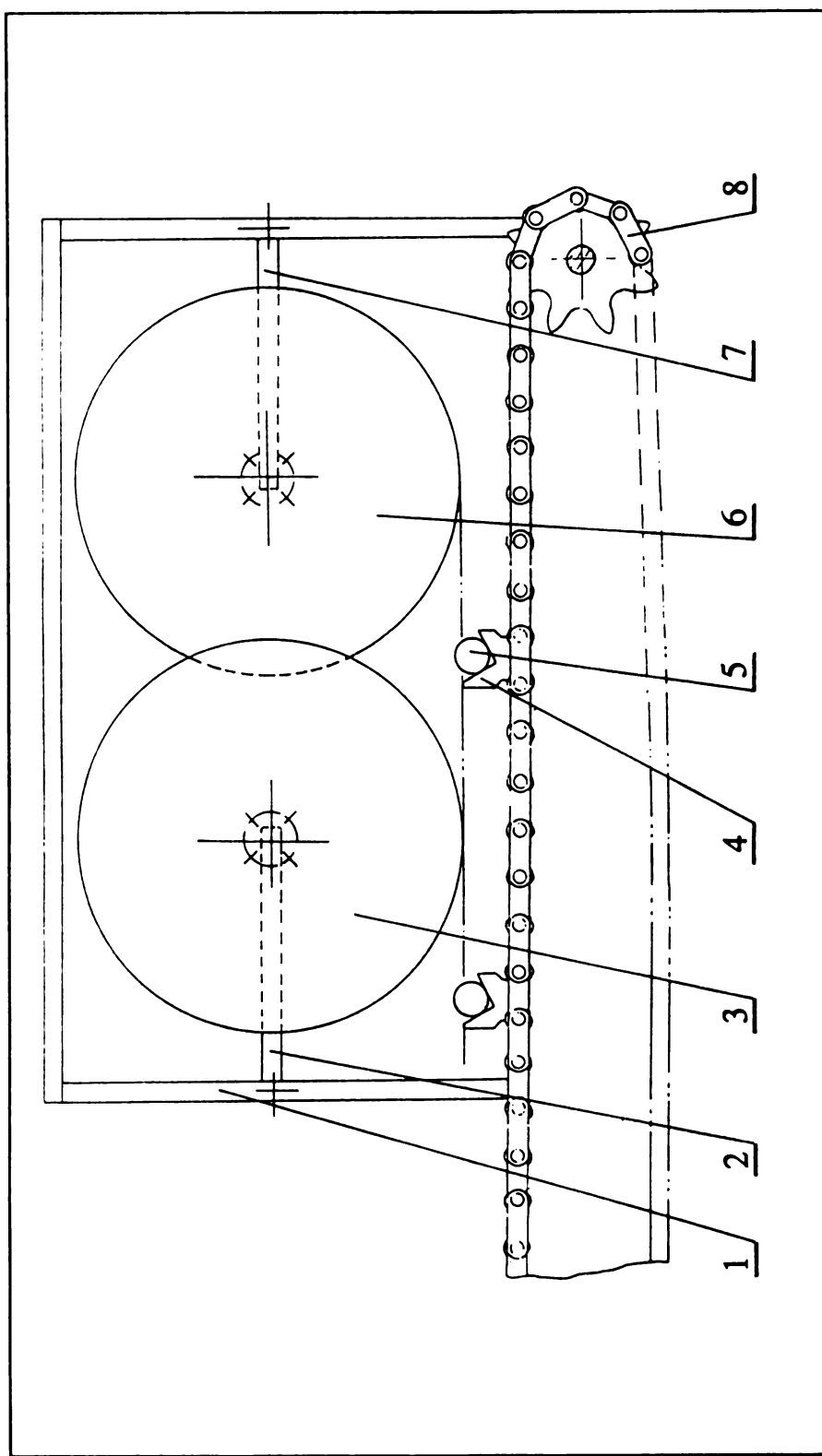
The onion's fibre is stratified in a longitudinal direction and, extends from the root to the stem. By cutting off its root and top portion, one severs the fibre. In addition, the composition of an onion is approximately 88% moisture (Ikram, 1971). Therefore, after ends cutting, because of the severing of the fibre, there is loss of moisture, and also, due to the release of existing tension in the outer-layer, the outer-layer shrinks towards the middle portion or equatorial portion faster than the fleshy bulb does. In this circumstance, if we add two slits on the onion surface, the peeling efficiency is greatly increased.

In addition, because of the variation of onions both in their shape

and size, in order to cut the top and root portion properly, the space between the two disc cutting saws should be varied to accommodate onions individually. Furthermore, considering peeling efficiency and peeling loss, the equatorial slitting length and the slitting depth which covers the equatorial portion should be controlled properly.

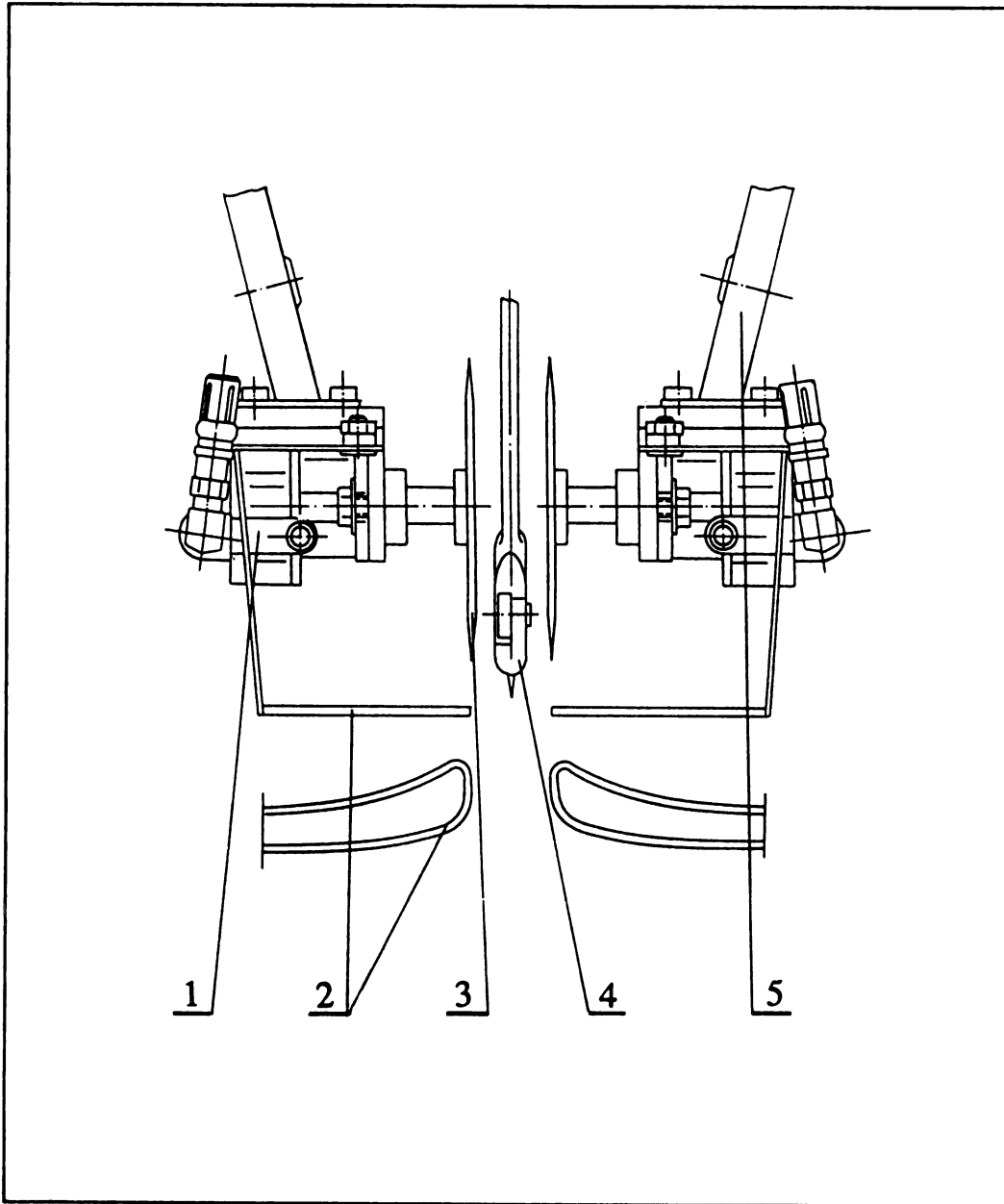
In addition, because the onion contains a number of acids as well as pectin, mucilage and acid sol. ash (Ikram, 1971), the slitting blades should be replaced easily by standard ones and, compressed air should be employed effectively to loosen the outer-layer from their fleshy bulb.

Based upon the above considerations the technological process in this stage is designed as follows: the onion is carried by the receptacle passing through the ends-cutting and equatorial-slitting station. First, the onion engages a pair of parallel vertically installed hold-down wheels. As shown in Figure 33, these wheels are suspended on the frame of the machine with rocking arms, and can be moved by onions up and down freely in a vertical direction. With the help of gravity, the hold-down wheels hold the onion in the receptacle firmly. Almost at the same time, the onion engages a pair of feelers which are solidly connected with the ends-cutting knife assemblies, as shown in Figure 34. The onion's shoulder pushes the feelers apart from their pre-determined position depending on its size and shape. The feeler and the end-cutting knife assemblies are suspended on the framework of the machine and can be moved by the passing onion freely in the transverse direction of travel. When the held onion continuously travels forward, it engages two parallel arranged vertically rotating disc saws, and two pre-determined slitting blades, as



1. Machine framework 2. Rocking arm 3. Ends cutting and equatorial slitting hold-down wheel 4. Receptacle 5. Onion 6. Longitudinal slitting hold-down wheel 7. Rocking arm 8. Conveying chain

Figure 33 The conveying-holding system of the MSU Machine



1. Ends cutting knife hydraulic motor 2. Self-regulating feeler
3. Ends cutting knife disc saw 4. Equatorial top slitting knife
assembly 5. Ends cutting knife assembly suspension

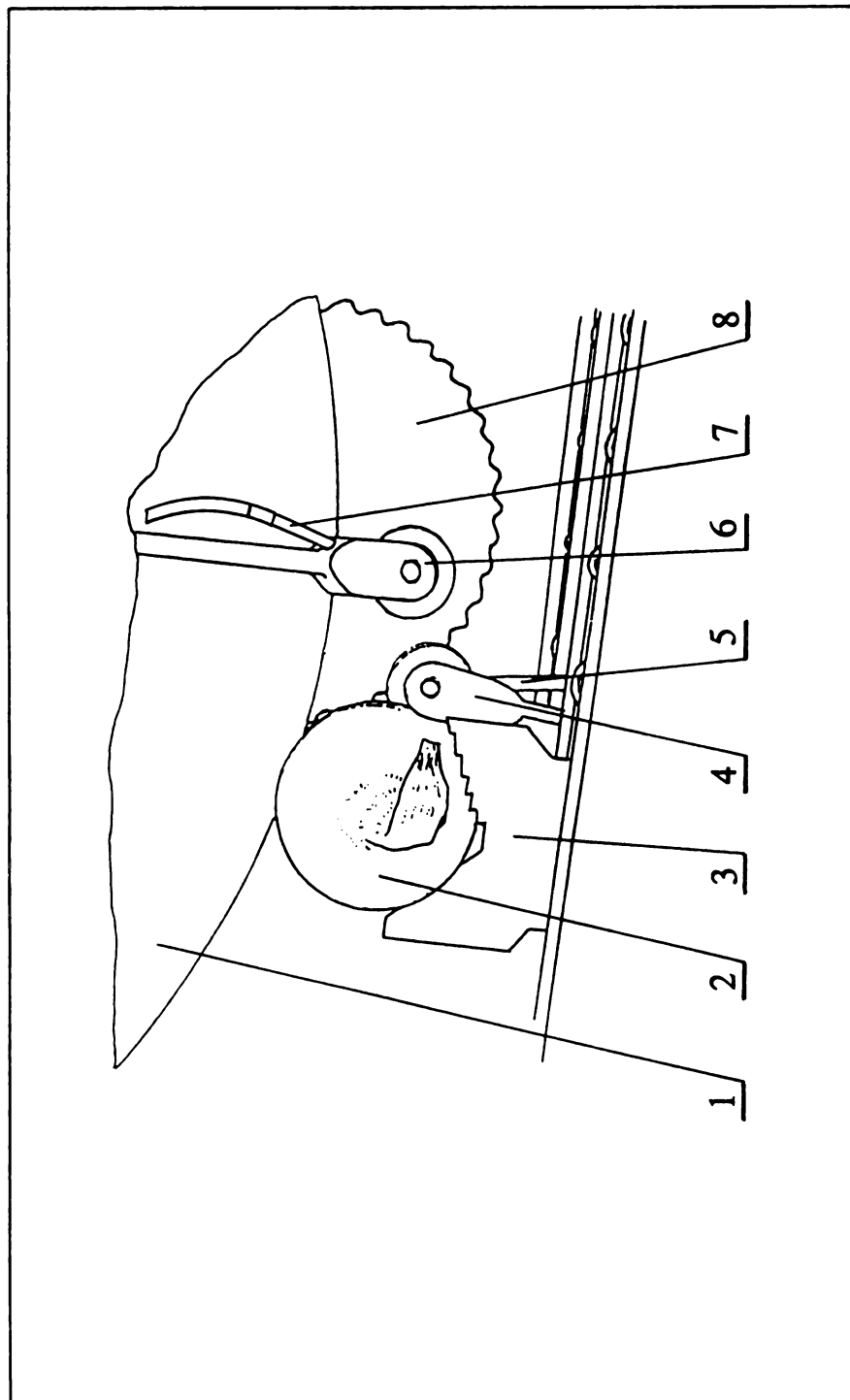
**Figure 34 The construction of ends-cutting and equatorial
slitting station of the MSU Machine
(Bottom equatorial slitting knife assembly is removed)**

shown in Figure 34 and Figure 35, first the bottom one, then the top one. These blades are placed vertically in the center of the path of the onion and forced by tension springs into a pre-determined position. After the onion passes through the station, its ends are cut off by the rotational disc saws, and two equatorial slitting are made by the slitting blades in its equatorial portion.

There are two compressed air jet nozzles beside the slitting blade. As shown in Figure 36, when the slitting blades cut the outer-layer of the onion, the compressed air jets loosen the outer layers immediately.

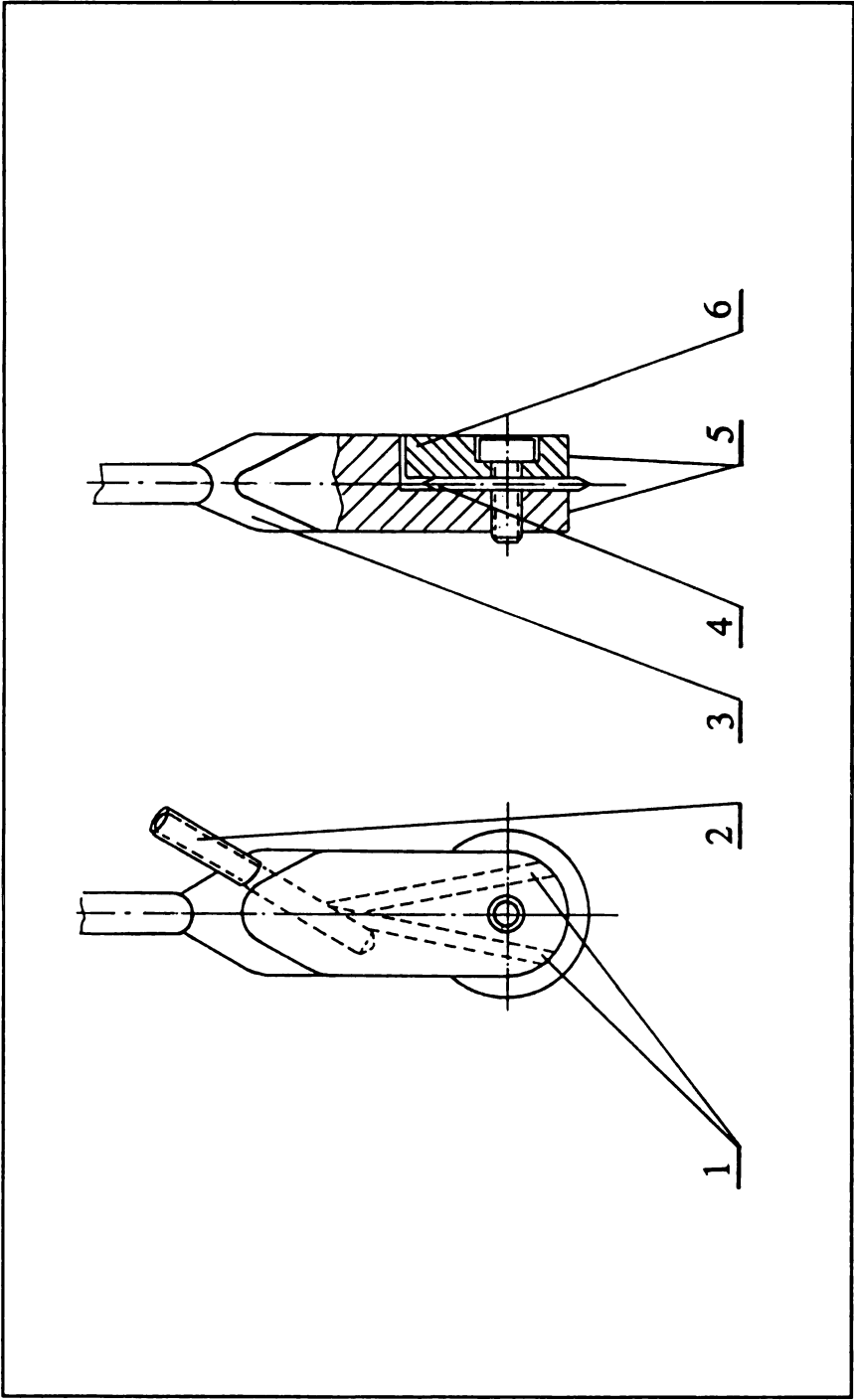
In the Fourth stage, the technological requirement is to make a completely longitudinal slit on the middle front of the onion. However, the thickness of the outer layers are varied in a longitudinal direction; they are thickest in middle portion and thinnest in each end portion. So, the slitting depth should be varied to follow the variation of the thickness of the outer layers. In addition, the slitting blades should be easily replaced by a standard one. Compressed air jets should be employed effectively to further loosen the outer layers from their flesh bulb.

During processing, the onion carried by the receptacle first engages a vertically installed hold-down wheel, as shown in Figure 33. Gravity helps the hold-down wheel to hold the ends-cut and equatorially-slit onion firmly on the receptacle, the hold-down wheel which is suspended on the frame of the machine with a rocking arm and which can be moved by the onion freely up and down in a vertical direction. Then, the ongoing onion engages two slitting blades, as shown in Figure 37, one on the left side and another one on the right side, horizontally placed in the middle of the onion



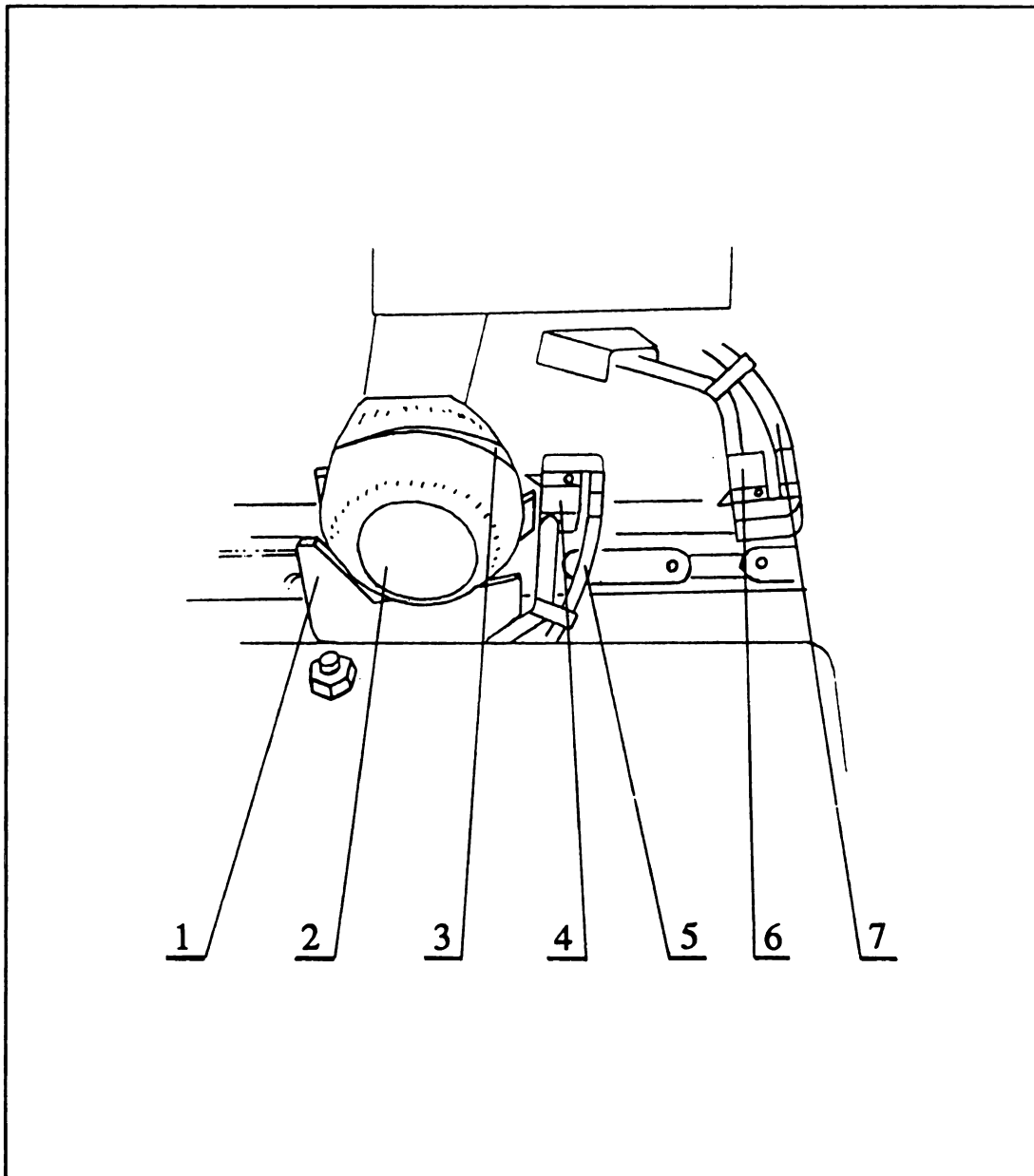
1. Ends cutting and equatorial slitting hold-down wheel 2. Onion 3. V-shaped notch receptacle 4. Equatorial bottom slitting knife assembly 5. Compressed air tube 6. Equatorial top slitting knife assembly 7. Pressure air tube 8. Ends cutting disc saw

Figure 35 A side view of ends cutting and equatorial slitting station of the MSU Machine
(One ends cutting disc saw and one hold-down wheel are removed)



1. Build-in compressed air jet nozzle 2. Air jet in-let 3. Knife carriage 4. Equatorial slitting disc blade 5. Knife shoulder 6. Blade clamp

Figure 36 The construction of equatorial slitting knife and build-in air jet nozzle of the MSU Machine



1.V-shaped notch receptacle 2.Ends cut onion 3. Equatorial top slit
4.Longitudinal right slitting knife assembly 5.Compressed air tube
6. Longitudinal left slitting knife assembly 7.Compressed air tube

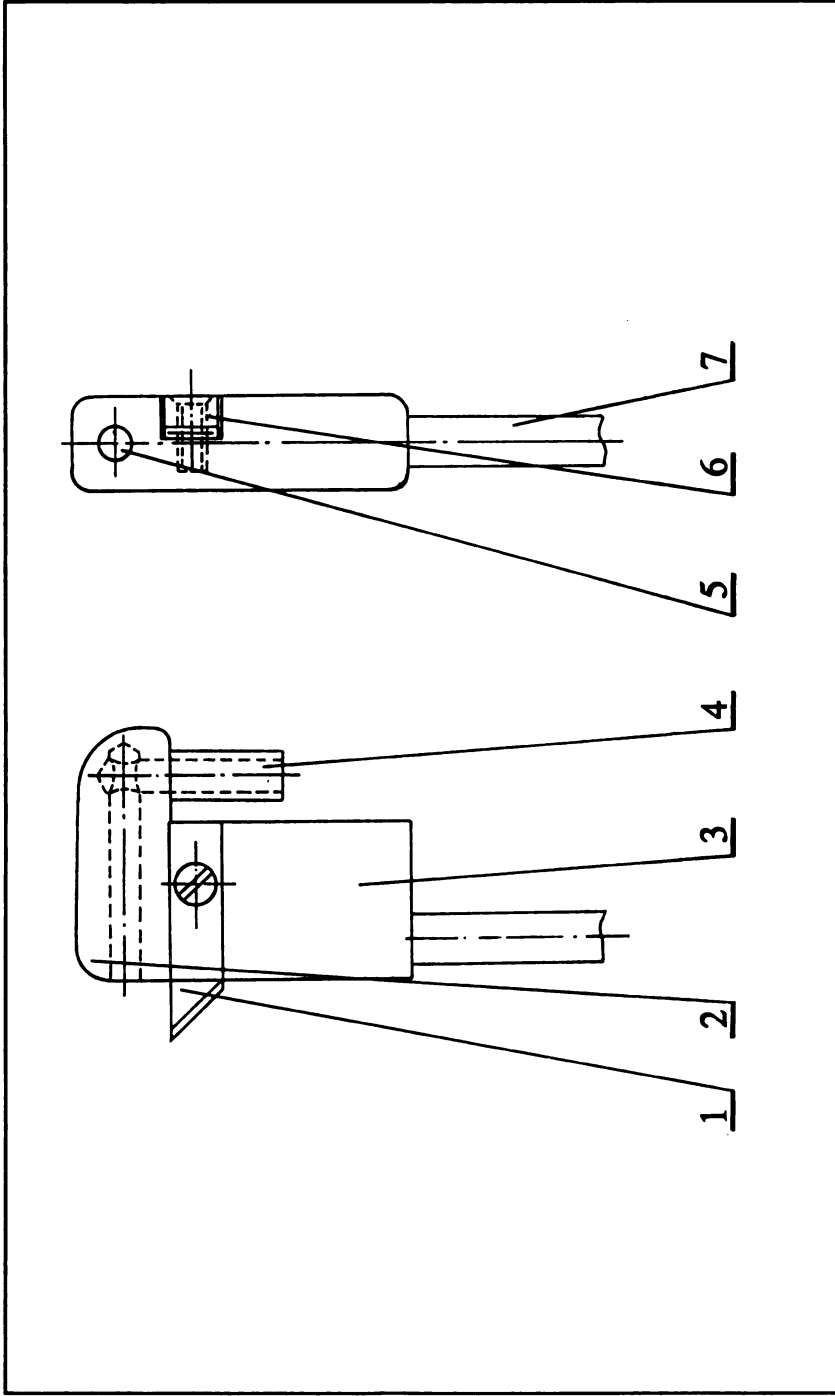
**Figure 37 The construction of longitudinal slitting station of the
MSU Machine
(Hold-down wheel is removed)**

path. After the onion passes through the station, the blades slit the front side of the onion in a longitudinal direction. The compressed air jet nozzle is set beside the slitting blade, as shown in Figure 38, and when the slitting blades cut the outer layers of the onion, the compressed air further loosens the skin.

In the Fifth Stage, since the loosened outer layers are still mixed with the fleshy bulbs, it is needed the machine to separate the broken and loosened peels from the flesh bulbs and send the bulbs to next station. A roller separator and three compressed air jet nozzles are employed to accomplish this process. In the processing, the onion (its ends cut, equatorially- and longitudinally-slit and outer layer-loosened) is moved to the end of conveyor by receptacle and dropped into an inclined roller type separator, as shown in Figure 39. The centrifugal effect and the friction force, which are created by the high speed rotated rollers, combine with the compressed air pressure, cause the loosened outer-layers of the onion to be further peeled or stripped and, the broken peel pieces are blown off and sent by the rollers out of the separator through the gap between the two rollers. The bulbs are spun off from the outer layers and rolled down to the exit of the separator.

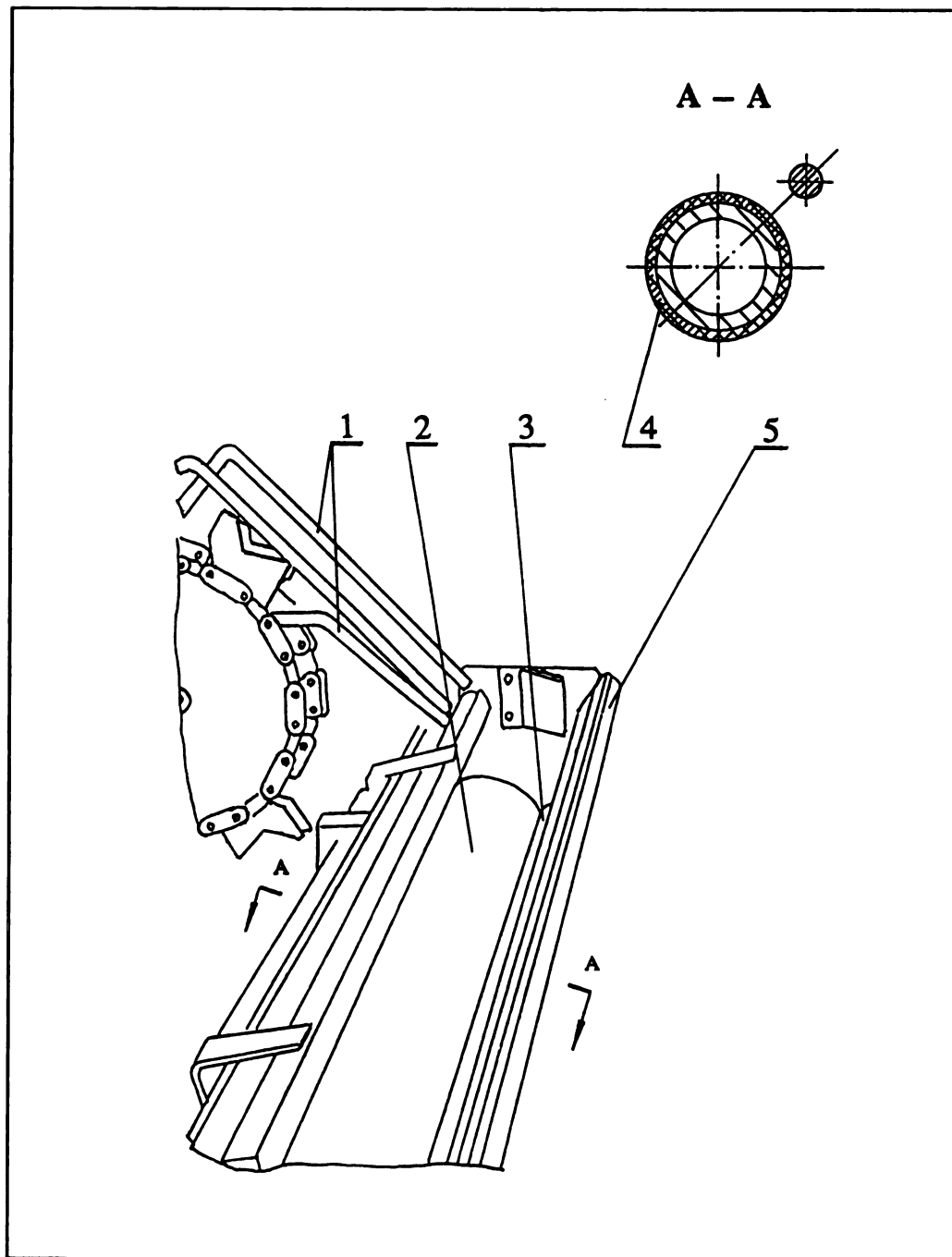
In the Sixth Stage, the peeling quality is inspected by eye and all damaged, diseased, bruised and discolored or defective portions are removed by hand.

In the Seventh Stage, the qualified onions are put on a conveying belt to pass through several water jets, where all dirt is washed off.



1. Longitudinal slitting blade 2. Knife shoulder 3. Knife carriage 4. Compressed air in-let
5. Compressed air nozzle 6. Clamp 7. Knife rod

Figure 38 The construction of longitudinal slitting knife and build-in air jet nozzle



1. Onion dropping guides 2. Friction roller 3. Stainless steel roller 4. Rubber cover 5. Separator framework

Figure 39 The construction of separating station of the MSU Machine
(Air jet nozzles are removed)

In the Eighth Stage, the completely peeled and cleaned onions are packaged and weighed for shipping, or for temporary cold storage.

3.3 The Construction of The MSU Machine

The MSU onion peeling machine consists of six major mechanical systems: (1) Hold-down and conveying system, (2) Ends-cutting system, (3) Slitting knife system, (4) Separating system, (5) Compressed air system, and (6) Hydraulic system.

The MSU Machine has the following advancements. First, the MSU Machine uses simple and reliable mechanisms to accomplish multiple outer-layer slitting (equatorial and longitudinal). Second, a self-regulating technique is employed in holding, ends-cutting and slitting. Third, a compressed air jet peeling technique is efficiently applied in slitting and separating. Fourth, the whole machine system is driven and controlled by a hydraulic system.

The MSU Machine not only is advanced, but also practical. The practicability is mainly displayed in its compact construction, simple and durable mechanisms, effective performance and economical cost.

Some advanced techniques often are employed in different functional mechanisms in the MSU Machine. For instance, the technique of self-regulating is not only applied in the ends-cutting system, but also in the hold-down wheel and slitting mechanisms. In addition, in the machine, the accomplishment of some process technologies employs not just one technique, but frequently the synthesis of multiple techniques. For example,

equatorial and longitudinal slitting not only depend upon the slitting knife system, but also upon the association of a specially designed receptacle and conveying system.

3.3.1 Multiple Slitting in The MSU Machine

Equatorial and longitudinal slitting on the onion's outer layers are important features in a farm onion peeling machine. In previous machines, most had only one outer layer slitting (longitudinal slitting), such as, BUCK Machine, Figure 13, (U.S. Pat. 3,623,524, 1971). CLYMA Machine, Figure 16, (U.S. Pat. 4,476,778, 1980) and even GREEN Machine, Figure 9, (U.S. Pat. 4,068,011, 1975). Although the MELLON Machine (Figure 8, U.S. Pat. 3,696,848, 1970) had both complete equatorial and longitudinal slitting, it used a complex mechanical system (two sets of slitting knives plus two separated conveying chains, a pair of holding chains and one rack rotating mechanism). And, the procedure of processing was not continuous.

The main difficulty in realizing both equatorial and longitudinal slitting in onion peeling is the interference between the holding system and the multiple slitting assemblies. That is the holding system obstructed the path of the equatorial or longitudinal knife assemblies to make free slitting on the onion's surface. The MELLON Machine adopted a procedure which rotated the onions to be able to make do with equatorial slitting knives. Consequently, the complex mechanical system not only increased the cost and decreased the reliability, but also decreased the suitability, because, the space between the two onion holding chains were fixed, which is suitable only for certain size onions.

In order to avoid the interference between the equatorial slitting knife assemblies and the holding system, the MSU Machine uses a pair of equatorial knife assemblies on opposite sides in the vertical center of the onion path. The pair can swing in a vertical plane, as shown in Figure 34 and Figure 35. And, the machine employs a specifically designed conveying-holding system, as shown in Figure 33. The system consists of a pair of extended pitch roller chains which are driven by a pair of cluster sprockets. A pair of V-shaped notch plate receptacles are fixed with certain corresponding links of the chains. A pair of parallel hold-down wheels are separately arranged and suspended vertically on the frame by a pair of rocking arms.

The onion is carried by the V-shaped notch receptacle from one stage to another. When it reaches the ends-cutting and equatorial-slitting stage, it engages a pair of hold-down wheels (being pressed on top) and is held by the two plates of the receptacle (being supported on the bottom firmly to engage the pre-determined slitting knife members). Between the pair of hold-down wheels there is a space which allows the top member of equatorial slitting knife assembly to freely swing vertically between them. And, also, since there is a space between the pair of plate type receptacles and the pair of chains, the bottom blade of equatorial slitting knife assembly can freely make low-half equatorial slits from the bottom side, and the top blade of the equatorial slitting knife assembly can freely make a top-half equatorial slit from the top.

In order to realize the longitudinal slitting, a pair of longitudinal knife assemblies are installed on opposite sides in the horizontal center

of the onion path, as shown in Figure 37. The pair swing in a horizontal plane. Since the front corner of the V-shaped notched plate is designed lower than the level of the longitudinal knives, the pair of blades of the longitudinal knife assemblies can make slits on the surface of the middle front of the onions without any obstruction when they are carried by the receptacle to engage them.

From above description, we can see that the MSU Machine not only obtains the desired equatorial and longitudinal slits, but also the performing systems are simple, reliable and practical.

3.3.2 Self-Regulating Technique in The MSU Machine

The characteristics of the processing object, the onion, which varies both in shape and size, dictates that the application of a self-regulating technique becomes a criterion in the performance evaluation of a farm onion peeling machine.

The MSU Machine successfully applies a self-regulating technique in (1) Holding, (2) Ends-cutting and (3) Slitting.

In Holding, the self-regulating technique is utilized in two progressing stages, Ends-cutting and Equatorial and Longitudinal Slitting. In both of these stages the onion is held in place by hold-down wheels and the receptacle.

In the Ends-cutting and Equatorial Slitting Stage, a pair of parallel wheels are arranged vertically to hold down the onion onto the receptacle.

Each hold-down wheel is suspended on the frame of the machine with a rocking arm. Ball bearings are used to connect the arms with the wheels and the frame. When the onion passes under the wheels carried by the receptacle, the wheel can rotate around the arm-wheel joint and the arm can be moved by the onion up and down in a vertical direction rocking around the arm-framework joint. Because of gravity, the hold-down wheels always hold the onion in the receptacle firmly, whatever the size and the shape of the onion.

In the equatorial slitting stage, a single identical hold-down wheel is used to hold all kinds of onions firmly in the receptacles when they pass under the wheel.

In the Ends-cutting process, a pair of feelers are installed in the onion path which are solidly connected to a pair of end-cutting knife assemblies and can be pre-adjusted relatively to ends-cutting assemblies. The assemblies are suspended on the frame with a falling hinge through a pendulum arm. The arm can sway around the arm-framework joint in a transverse direction to the onion's travel and is pre-forced by a tension spring. When an onion engages the pair of feelers carried by receptacle and held by the wheels, the onion's shoulder pushes the feelers apart from their pre-determined position in the transverse direction of travel, adjusting the space between the disc cutting saws. Whatever the size and the shape of the onion, the amount of cut off from onions always is pre-determined.

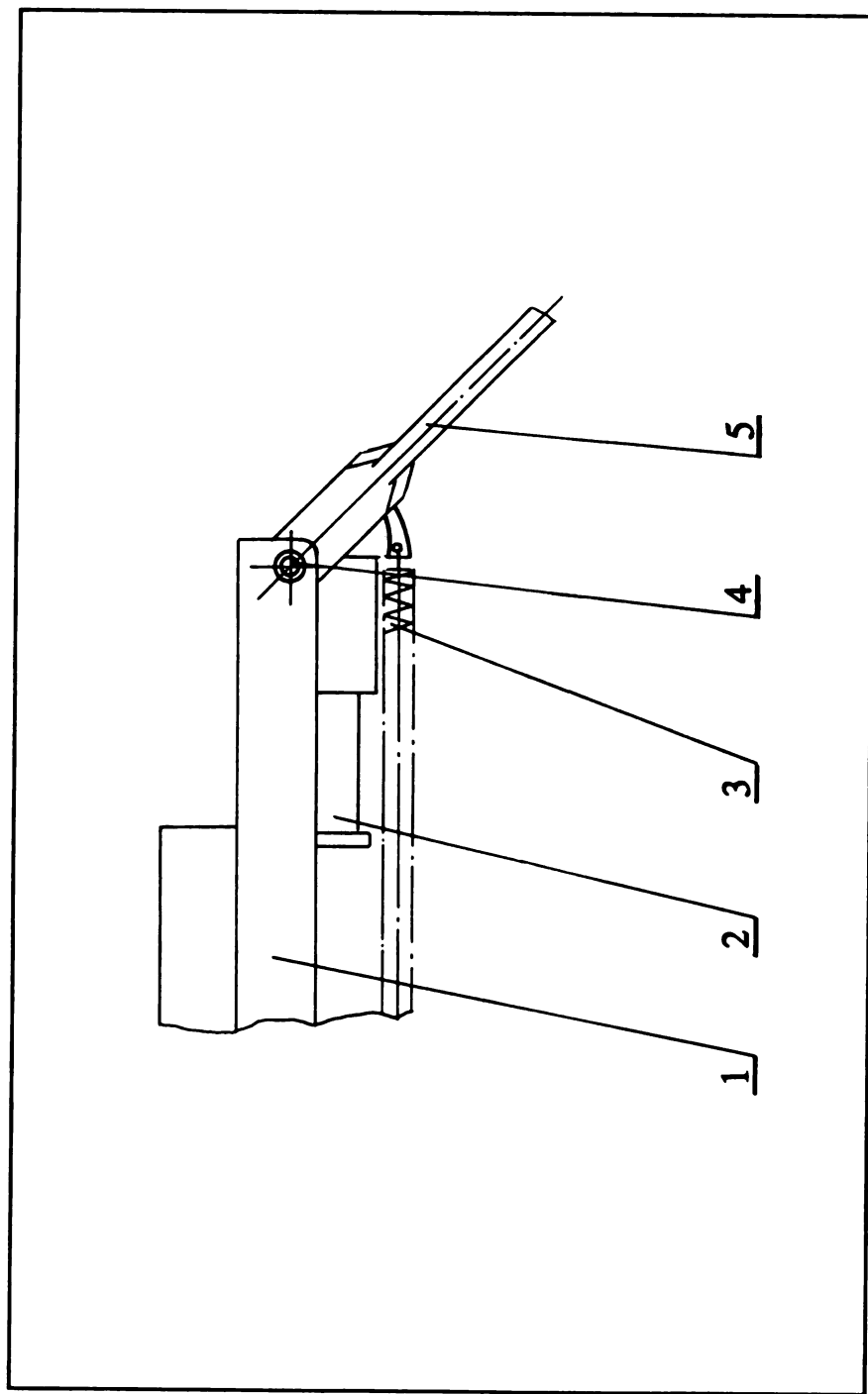
The self-regulating technique also is applied in both the equatorial and the longitudinal slitting process, wherein two pairs of slitting knife assemblies are installed on opposite sides in the center of the onion path.

The members can swing in a vertical plane for equatorial slitting and a horizontal plane for longitudinal slitting when they are engaged by an onion, as shown in Figure 35 and Figure 37, respectively.

The key point of a self-regulating technique in the slitting process is its suitability, that is how well the locus of the slitting blade suits the contour of the onion (which varies individually in size and shape). This problem also exists in the design of the cutting and holding self-regulating mechanisms. But in those cases, the measuring or feeling which is required is only a point or a straight line, that is, the touch of the feeler with the onion is only a point or straight line touching. However, in the slitting process, it needs a curved touching or measuring. The MSU Machine has developed successfully the technique in the onion slitting process with specially designed slitting knife assemblies. Since the assemblies have similar construction, only the equatorial top slitting assembly is discussed here. The construction of the assembly is shown in Figure 40.

The equatorial top slitting knife assembly consists of one tension spring, one knife rod component and one hydraulic buffer. In processing, the onion is carried by a receptacle which makes a rectilinear invariable motion, and the knife rod component functions by a tension spring which makes the slitting blade remain in touch with the contour of the onion. The knife rod is moved by the onion's rocking around a rod-cantilever pivot. The slitting blade makes a curve on the onion's surface in a central vertical plane from the middle front point to the middle back point.

In order to avoid over cutting in the process of equatorial slitting, particularly at the beginning of the slitting when onion dashes against the



1. Machine framework 2. Hydraulic buffer 3. Tension spring 4. Pivot
5. Equatorial top slitting knife rod assembly

Figure 40 The construction of equatorial top slitting knife assembly of the MSU Machine

slitting knife, a shoulder is designed on the knife carriage. And, the beginning position of knife carriage is pre-determined in a vertical position as shown in Figure 36.

When the top slitting blade passes the top point of the onion, it cannot engage the top slitting blade continuously. In order to help continuing the slit on the backside of ongoing onion, the MSU Machine adopted a disc blade in the equatorial slitting knife as shown in Figure 36.

In longitudinal slitting, the depth of slitting must vary with the thickness of the outer layers in an equatorial direction. A specially shaped shoulder is designed on the knife carriage. The shape of the shoulder associated with the motion of the carriage makes the depth of the slitting vary with the thickness of the outer layer in an equatorial direction, and thus the depth of the cut is controlled.

A hydraulic buffer is added to produce a cushioning effect and to absorb the shock when the downward-moving slitting rod stops quickly for the oncoming onion.

3.3.3 The Application of Compressed Air Jet Peeling in The MSU Machine

The compressed air jet is an important feature in onion machine peeling both from the standpoint of the history of the development of the onion peeling machine and the economical benefits of compressed air technology. The MSU Machine has successfully applied the technique in slitting and separating process, and, has developed the application of the

technique to a new level.

In past years, people have realized the advantages of the compressed air jet in onion peeling, even though peeling efficiency is not high. The problem is that the compressed air has not been utilized effectively. In order to increase peeling efficiency using compressed air, the MSU Machine employs a type of specially designed air jet nozzle in the onion slitting process. The novel air jet nozzles are built within the slitting knife assemblies and are arranged just beside the slitting blades. When the slitting blade slits the outer layers of the onion, the compressed air jet loosens them immediately. The construction of the slitting knife assembly with the air jet nozzle is shown in Figure 36 and Figure 38.

In the slitting process, following the slitting blade a jet of compressed air penetrates the outer layers of onion through the slit made by the blade. The air pressure causes the outer layers to loosen from the fleshy bulb. Because the compressed air jet is working together with the slitting blade and very close to the slit, the compressed air is extremely effective.

In the separating process, three air jet nozzles function together with the rollers. They are arranged along the length of the roller and towards the gap between the two rollers. When the ends are cut and the outer layers are slitted and loosened, the onion is dropped into the rollers, and the broken peels are blown off by the compressed air jets and swept away by the rollers.

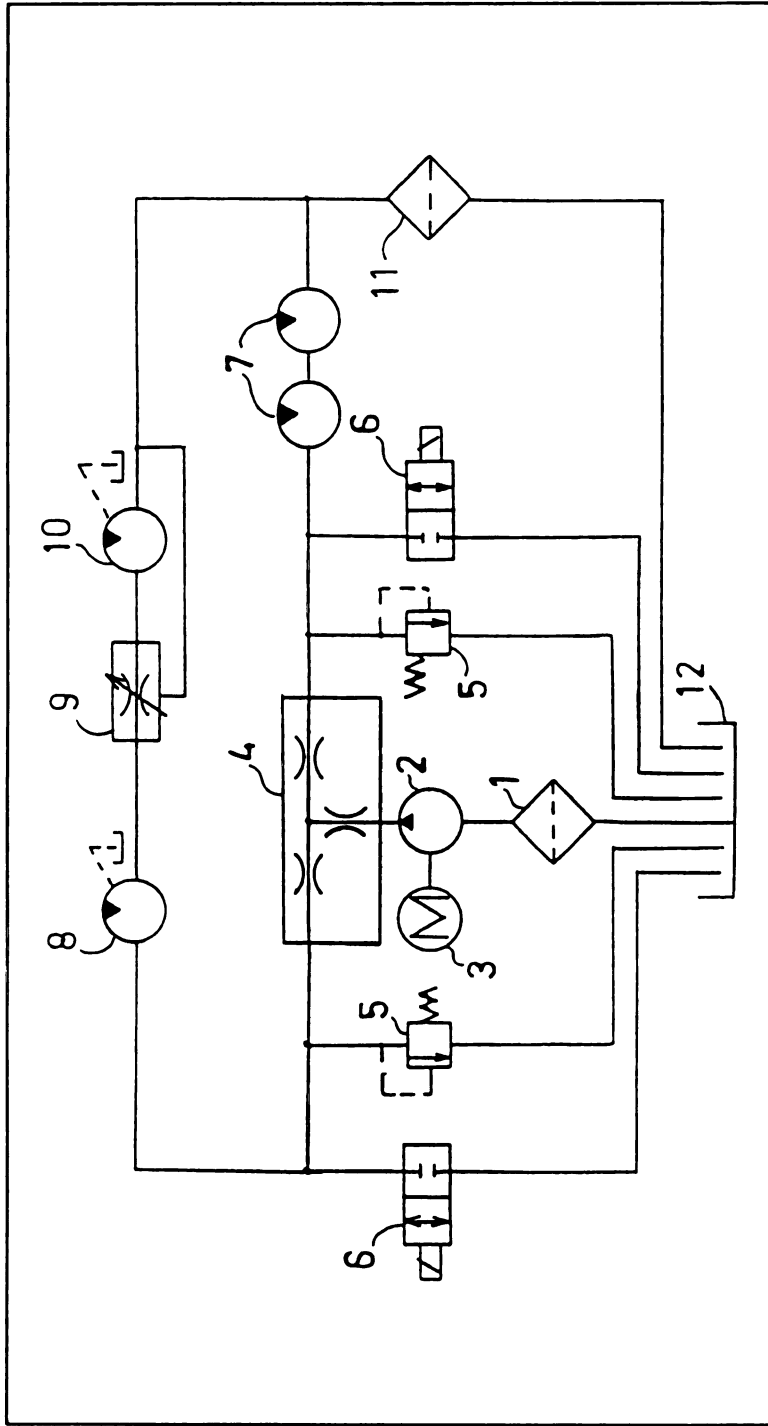
3.3.4 Hydraulics in The MSU Machine

The spattering of washing water and onion juice (which contains a number of acids) when the onion is cut, slit and peeled creates a wet and corrosive environment in which the MSU machine must operate. A completely hydraulic power and control system was adopted to fulfill the requirements of safety for the machine's operation and maintenance. In addition, the hydraulic components and system have the advantage of efficiency, economy and dependability in the farm onion peeling machine.

The MSU Machine is powered by a hydraulic power pack. The hydraulic circuit is shown in Figure 41. The system utilizes a vane pump with a priority flow divider. One flow is directed to the two ends of the cutting motors connected in series. Another flow is used to drive the separator rollers and the return flow is used to drive a conveying chain motor through a low valve to control the chain speed. A pair of adjustable pressure relief valves and a two-way direction valve are installed in both sides of the flow divider valve to fully unload the pump in the event of an emergency shut down. In addition, a suction screen is installed on the inlet line of the pump and a filter is used in the return line.

3.3.5 Safety Features in The MSU Machine

Safety measures are fully considered in the design of the MSU Machine. In addition to adopting the hydraulic power and control system, at the end of the chain conveyor, the outside of the ends-cutting stage and the conveying chains are all covered. The feeding station is designed far



1. Suction screen 2. Vane pump 3. Electric motor 4. 55/45 flow divider 5. Adjustable pressure relief 6. 120 V solenoid two-way valve 7. Cutting motor 8. Separator drive motor 9. Adjustable flow control valve 10. Conveying chain drive motor 11. Return line filter 12. 38 liter reservoir

Figure 41 The circuit diagram of the hydraulic system of the MSU Machine

away from the moving components. Before the ends-cutting stage a protective gate is added, and in its design the MSU Machine widely adopts passive performing components in loading, ends cutting and the two types of slitting. Finally, a compressed air jet is used to increase the safety both of the onion products and the operator.

CHAPTER IV

QUANTITATIVE EVALUATION OF THE MSU MACHINE

4.1 Introduction

This chapter is devoted to the quantitative evaluation of the performance of the MSU onion peeling machine. The evaluation was based mainly on a sequential statistical investigation.

Because the MSU onion peeling machine is a newly developed machine system and its performance is a complex multi-factor case, it cannot be represented or analyzed satisfactorily by theory-derived models. Consequently, two statistical experiments were conducted on the second prototype of the machine, and Response Surface Methodology (RSM) was used to build empirical models to simulate the machine system approximately. The purpose of this approximation was not to represent the true underlying relationships everywhere, but merely to graduate them locally in the experimental regions. Presented in this chapter is the second experiment, which was designed and performed based upon the previous plant's experience and the conclusions summarized from the first experiment.

In the first experiment of the MSU onion peeling machine (Wang, 1992), a factorial design was conducted to test only two independent variables, chain speed (10, 13 and 24 M/min.) and onion size (60, 82.5 and 95

mm), each in three levels. Two responses, peeling efficiency and total peeling loss were observed. Another independent variable, air pressure, was kept constant (517 kpa). However, the factor of onion shape was not considered in the experiment. The raw data table and the results of the analysis of variance are presented in Appendix A. The results of the experiment indicated that both Chain speed and Onion Size were significant to peeling efficiency and total peeling loss. In addition, the results showed that the interaction of chain speed and onion size was significant in total peeling loss.

In order to further test the onion machine peeling system, second experiment was designed and conducted in the onion peeling plant, in Spring of 1992. In this experiment, four independent variables, onion shape, onion size, air pressure and chain speed were tested. Three responses, machine peeling loss, total peeling loss and peeling efficiency, were investigated to perform a response surface routine analysis by the analysis of variance as well as computer generated response surfaces and their contour plots.

In this study, extra response surface designs were conducted based upon the data collected from the second experiment. A computer interfaced backward elimination selection procedure was conducted to determine the "best" polynomial equations. Canonical analysis was used for judging the location of possible limit values (maximum, or minimum, or saddle) and computer superimposing method was used to search the optimal operating conditions which satisfy for both of the models of peeling loss and peeling efficiency locally. The objectives of this study were to: (1) better understand the relationships between the factors affecting the machine

peeling system and the responses determining the effectiveness of the process, and (2) determine a set of optimal operating conditions for the existing machine system to attain the maximum processing benefits.

4.2 Variable Definitions

There were four independent variables and three response variables considered in this study. The independent variables were onion shape, onion size, air pressure and chain speed, and the response variables were machine peeling loss, peeling efficiency, and machine peeling capacity. These are defined and discussed below.

4.2.1 Definition of Three Response Variables

The performance of the onion peeling machine was characterized by three response variables: machine peeling loss (MLoss), peeling efficiency, (E), and peeling capacity (C_p). Since onion varies with its weight (mass) individually, the variables of machine peeling loss and peeling efficiency cannot be measured directly, and so, they were transferred as the functions of the initial weight, W_i (kg), the machine peeling weight, W_m (kg), and the final weight, W_f (kg). The weights were measured by an electronic scale directly.

(1) **Machine Peeling Loss:** Machine peeling loss was defined as the amount (weight) of peels removed by the machine in proportion to the initial onion weight. This reflects exactly the amount of peels removed by the machine per unit weight of onion. The challenge is to have high peeling

effectiveness while keeping the machine peeling loss to a minimum. The following equation was used to calculate machine peeling loss:

$$MLoss = \frac{W_i - W_m}{W_i} \times 100 \quad (4.1)$$

where MLoss = machine peeling loss (%)

(2) **Peeling Efficiency:** Peeling efficiency was defined as the ratio of the amount (weight) of peels removed by the machine to the total amount (weight) of peels removed in the processing. This describes the peeling effectiveness directly, that is, it describes what percentage (or portion) of the effective or necessary peeling was done by the machine. Once again, the objective is to obtain a high value of peeling efficiency while keeping the weight loss to a minimum. Peeling efficiency was computed as follows:

$$E = \frac{W_i - W_m}{W_i - W_f} \times 100 \quad (4.2)$$

where E = peeling efficiency (%)

(3) **Machine Peeling Capacity:** Machine peeling capacity (kg/h) was defined as the total weight of onions processed by the machine in an hour. Since onions vary in weight, at a certain feeding rate different peeling capacities will result. This can be calculated as the sum of the individual weights of onions being processed per hour. For instance, the capacity of the round shape and medium size onion is calculated by using an average weight of the onions, as follows:

$$C_p = 0.15(\text{kg/onion}) \times 60(\text{min}) \times \text{Chain Speed}(\text{onions/min}) \quad (4.3)$$

Where C_p = Machine Peeling Capacity

0.15 (kg/onion) = average individual weight for round shape and medium size of pungent Michigan onion

4.2.2 Definition of Four Independent Variables

(1) **Onion Shape:** Onion shape was defined as the ratio of its equatorial diameter (d) and longitudinal height (h). There were three types of onion shape considered in the experiment. They were flat shape: $d/h \geq 1.2$; round shape: $0.8 < d/h < 1.2$ and oval shape: $d/h \leq 0.8$.

(2) **Onion Size:** Onion size was defined as equatorial diameter (d). There were three types of onion size considered in the experiment. They were, small size: 70 mm (2.75 in); medium size: 82.5 mm (3.25 in) and large size: 95 mm (3.75 in).

(3) **Air Pressure:** Air pressure was measured directly from the air pressure meter connected to the air control valve. There were three levels of air pressure used in the experiment. They were, low air pressure: 414 kpa (60 psi); medium air pressure: 517 kpa (75 psi) and high air pressure: 620 kpa (90 psi).

(4) **Chain Speed or Feeding Rate:** Chain speed was determined by counting onions passing per minute. There were three levels of chain speed set in the experiment. They were, low chain speed: 60 onions/min.; medium chain speed: 80 onions/min. and high chain speed: 100 onions/min..

The equatorial diameter (d) was measured by a set of pass-type scale. The longitudinal height (h) was measured by a general caliper. The air

pressure was determined by a air pressure control valve and the numerical values were read directly from the meter combined with the valve. The chain speed was determined by adjusting the hydraulic control valve and the numerical values were read directly from the meter combined with the control valve. After setting the values to each level of the independent variables, the measure errors in the data preparation comparing to the one of responses were very small, thus they were considered as constant distribution and were neglected. This treatment is thought to be reasonable is based upon the assumptions which are fundamentally used in the RSM.

4.3 Design of Experiment

In this investigation, three experimental plans were adopted from the family of three level designs: the Hoke D_6 design, the Box-Behnken design and the complete factorial design. The Hoke D_6 design and the Box-Behnken design were used to verify and replenish the complete factorial design.

A 3^4 factorial design seemed to be the natural choice for this experimental situation, for the following reasons: (1) The factorial design is an efficient method of experimentation, particularly in the primary research stage for taking a complete view of the mechanism of the system. (2) It provides a measure of interaction between the controlled variables. (3) An additional check, lack of fit, for the inadequacy of a linear model to represent the data can be provided by adding a center point to the design. (4) It allows the experiment to proceed with greater sophistication sequen

tially, if necessary, later on. (5) The experiment may be kept within a practical size limit by running the treatment combinations in balanced blocks (Box, Connor, Cousins and Davies, 1956). Therefore, a well-executed, unreplicated, full factorial experiment as the essential design is presented and discussed in this chapter.

The independent variables (ξ_i) were changed to coded variables (x_i) for practical convenience by the following linear equation:

$$x_i = \frac{2(\xi_i - \bar{\xi}_i)}{d_i} \quad (4.4)$$

where,

ξ_i = actual value in original units

$\bar{\xi}_i$ = mean of high and low levels of ξ_i

d_i = spacing (difference) between the low and high level of ξ_i

The independent variables (ξ_i), the coded variables (x_i) and their levels are presented in Table 7.

The decision for the levels of the independent variables was based on preliminary work done by the author and Dr. Srivastava (Wang, Dec. 1991 and Wang, Mar. 1992) and onion peeling plant practical experience.

A sample size of 30 onions was used for each experimental run. In the experiment, well prepared onion samples were run in randomized blocks. The blocks were built according to different onion shipping and storage conditions. First, the sample was weighed before feeding into the machine for recording the initial weight, W_i . Then, the sample was randomly fed into the machine. After the machine peeling, the machine

Table 7
Independent Variables and Their Levels

Independent Variables	Symbol		Levels	
	Coded	Uncoded	Coded	Uncoded
Onion Shape	x_1	Shape	1	Oval ($d/h \leq 0.8$)
			0	Round ($0.8 < d/h < 1.2$)
			-1	Flat ($d/h \geq 1.2$)
Onion Size	x_2	Size	1	Large (95 mm)
			0	Medium (82.5 mm)
			-1	Small (70 mm)
Air Pressure	x_3	Pressure	1	620 (kpa)
			0	517 (kpa)
			-1	414 (kpa)
Chain Speed	x_4	Speed	1	100 (onions/min)
			0	80 (onions/min)
			-1	60 (onions/min)

peeling weight, W_m was recorded. Then the onions were inspected and additional peels were removed as necessary by hand. Finally, after the hand peeling sample was weighed for the final weight, W_f . The response values of W_{ml} , E and C_p were computed from the data collected in the experiment using equations 4.1, 4.2 and 4.3.

4.4 Results and Discussion

4.4.1 Model Fitting

The Response Surface Design routine of the Statistical Graphics System (STATGRAPHICS Plus, 1992) was used to fit the second order polynomial equation. The experimental data and response surface design are shown in Appendix D.

A computer interfaced backward elimination selection procedure was conducted for selecting the "best" regression equations. The two terminated polynomial equations are shown as following:

Machine Peeling Loss Estimating Equation:

$$\begin{aligned}
 MLoss = & 26.27 - 1.59 x_2 + 5.86 x_3 - 5.58x_4 \\
 & + 1.04 x_1x_2 - 1.13 x_1x_3 - 2.46 x_1x_4 - 2.73 x_2x_3 \quad (4.5) \\
 & - 0.87 x_2x_4 - 1.66 x_1^2 + 6.55 x_2^2
 \end{aligned}$$

Machine Peeling Efficiency Estimating Equation:

$$\begin{aligned}
 E = & 80.21 - 1.17 x_2 + 5.34 x_3 - 7.45 x_4 \\
 & - 3.60 x_1x_4 - 1.61 x_2x_3 + 1.38 x_2x_4 + 2.61x_3x_4 \quad (4.6) \\
 & - 2.50 x_1^2 + 3.68 x_2^2 + 1.64 x_4^2
 \end{aligned}$$

The results of the analysis of variance for the two terminated response models are presented in Table 8 and Table 9, respectively.

From the tables, one finds that almost all the remaining independent variables and their interactions are significant at a high level. The values of R^2 , R_a^2 and MSR were adjusted to the best conditions. The treatment of blocking was significant only in the model of machine peeling loss. However, the blocking for the model of peeling efficiency still exhibited some effects to improve the model, so they still remain in the model. Onion shape (x_1) was eliminated, since it was not significant independently in both models. But, its significance effectiveness appeared in combination with other variables. Some variables and their interactions were still kept in the

Table 8
Analysis of Variance for Machine Peeling Loss (W_{LM})

Effect	SS	DF	MS	F	P
x_2 : Size	136.32667	1	136.3267	11.80 ***	0.0010
x_3 : Pressure	1853.86963	1	1853.8696	160.45 ***	0.0000
x_4 : Speed	1682.25852	1	1682.2585	145.59 ***	0.0000
x_1x_2	38.85444	1	38.8544	3.36 *	0.0711
x_1x_3	45.78778	1	45.7878	3.96 **	0.0505
x_1x_4	218.05444	1	218.0544	18.87 ***	0.0000
x_2x_3	268.96000	1	268.9600	23.28 ***	0.0000
x_2x_4	27.21361	1	27.2136	2.36 *	0.1295
x_1^2	49.55654	1	49.5565	4.29 **	0.0422
x_2^2	772.68173	1	772.6817	66.87 ***	0.0000
block	43.65932	1	43.6593	3.78 *	0.0561
block	4.56691	1	4.5669	0.40	0.5384
Total Error	785.70552	68	11.5545		
Error (Corr.)	5924.74321	80	* Significant at the level of 0.1.		
% Variability explained (R^2) = 88			** Significant at the level of 0.05.		
% of R_a^2 (adj. for d.f.) = 84			*** Significant at the level of 0.01.		

models, even though their P-value was greater than 0.05 (such as, x_2x_4 and x_4^2 in peeling efficiency model). Because eliminating them would decrease the value of R_a^2 and increase the value of MSR. The results presented in the tables of the analysis of variance will be further discussed in section 4.4.3. These two estimated models were used later on by computer to generate the response surfaces and their contour plots.

Table 9
Analysis of Variance for Peeling Efficiency (E)

Effect	SS	DF	MS	F	P
x_2 : Size	74.20167	1	74.2017	1.92	0.1708
x_3 : Pressure	1537.06685	1	1537.0669	39.70 ***	0.0000
x_4 : Speed	2994.15574	1	2994.1557	77.33 ***	0.0000
x_1x_4	467.28028	1	467.2803	12.07 ***	0.0009
x_2x_3	93.12250	1	93.1225	2.41 *	0.1256
x_2x_4	68.89000	1	68.8900	1.78	0.1867
x_3x_4	245.44444	1	245.4444	6.34 **	0.0142
x_1^2	112.33340	1	112.3334	2.90 *	0.0931
x_2^2	243.71414	1	243.7141	6.29 **	0.0145
x_4^2	48.12895	1	48.1290	1.24	0.2688
block	21.63358	1	21.6336	0.56	0.4653
block	11.41358	1	11.4136	0.29	0.5947
Total error	2632.84352	68	38.7183		
Total (corr.)	8582.19580	80	* Significant at the level of 0.1.		
% Variability explained (R^2) = 69			** Significant at the level of 0.05.		
% R_a^2 (adj. for d.f.) = 64			*** Significant at the level of 0.01.		

4.4.2 Diagnostic Checking

The models of peeling efficiency and machine peeling loss were checked in two aspects: (1) the relationship between the size of the residuals and the expected value of the responses; and (2) the normal distribution of residuals. The results are shown in Figure 42 (A through D).

First consider the plot of the residual and the predicted value.

Through a careful examination of each plot Figure 42 (A and C), that the model of peeling efficiency predicted the medium and the high values quite well, whereas, there were some slight larger residual values appearing in the area of low peeling efficiency. In the model of the machine peeling loss (plot C of Figure 42), only a few wild points irregularly appeared. In general, however, no specific pattern could be found between the size of the residuals and the estimated value. This indicates that the assumption of residuals distributed independently was tenable.

The normal probability checking, Figure 42 (B and D), shows some slight evidence that the parent distribution in the model of machine peeling loss (plot B of Figure), was not normal and probably had a slight heavy-tailed distribution at the left side of the curve and a light-tailed distribution at the right side. However, most residuals were distributed normally in Figure 42 (B and D); they are very closed to a straight line. This demonstrated that the assumption of normality of residual distribution was tenable.

Furthermore, the observed response value vs. the predicted value plots, the residuals vs. the run order plots, and the residuals vs. the individual factor plots were performed by screen checking on computer. No defective evidence has been found from checking these plots which indicates that the estimated models should not be acceptable.

Summarizing the diagnostic checking, and also, considering the results of the analysis of variance, R^2 , R_a^2 , MSR, P-value and F-value (presented in Table 8 and Table 9), as well as the lack-of-fit checking in the Box-Behnken design (presented in Appendix C), the conclusion is that these two

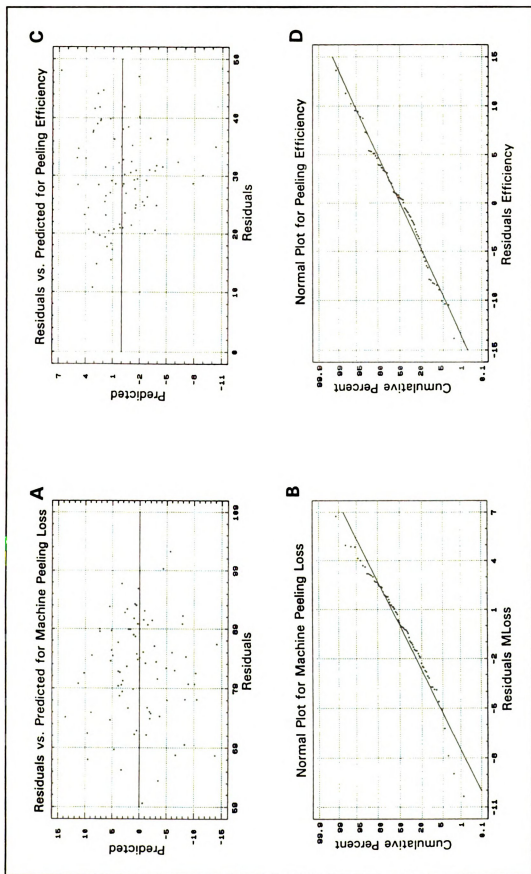


Figure 42 The diagnostic checking plot to the estimated models

estimated models are accurate enough to be acceptable for further use in the study.

4.4.3 Response Surface Interpretation

The computer generated response surfaces and their contour plots presented in Figure 43 through Figure 48 were obtained using the estimated models of MLoss and E presented as Equation 4.5 and 4.6, respectively. Such three-dimensional response surfaces and associated contour plots supplied accurate geometrical representation and provided useful information about the performance of the system within the experimental region. An analysis

of the surfaces and contour plots can enable us not only better understand visually the relationships between the factors affecting the machine peeling system, but also can further demonstrate the results obtained from the analysis of variance.

In the presentation of response surface, every time only two independent variables and one corresponding response can be generated by computer. Other two independent variables were held as constants. Theoretically speaking, they can be held at any level individually within the experimental region. In this study, they were always held at middle-level.

Figure 43 shows the plots for the model of peeling efficiency and that of machine peeling loss as affected by onion shape and size. From the surface plot of peeling efficiency, it is noted that the surface slopes from flat to oval, this indicates that the flat shape onions have a higher efficiency than

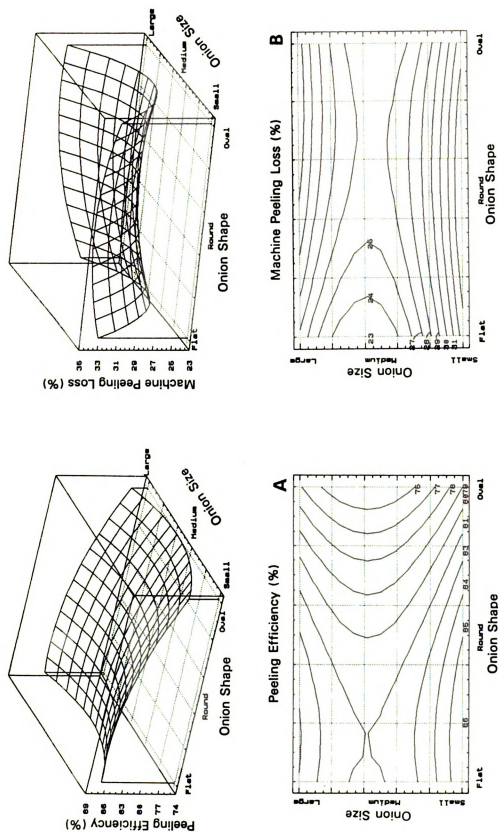


Figure 43 The response surface and contour plots of peeling efficiency and machine peeling loss as affected by onion shape and onion size

slopes in opposite direction, which indicates that the flat shape onions have lower peeling loss than the one of the oval shape onions. This is a desirable situation, because it indicates that the optimal area is located in the area between the flat shape and the round shape. This area has the highest peeling efficiency and the lowest peeling loss.

On the other hand, in both models, the surface raises from the middle to the sides, so that, the limitation (maximum) in both sides is out of the experimental region, or, there is no practical feasibility. However, the least peeling efficiency and the lowest peeling loss in terms of size can be found in the middle of the surface, which means that the optimal search area for the least peeling efficiency and the minimum peeling loss in terms of size are in the area around the medium size onions regardless the onion shape.

The above analysis shows that for the feasible peeling efficiency and the lowest peeling loss the optimal area in terms of onion shape and onion size is in the area of medium size and between flat shape and round shape.

Furthermore, in the efficiency plot, one finds that the surface appears parallel to the axis of the shape, which confirms the result of the analysis of variance, that is, that the interaction, x_1x_2 (shape and size), is not significant in the efficiency model. And, the curvature of the surface is not sensitive in terms of the onion shape and the onion size (notice the density of contour lines) confirming that both x_1 (shape) and x_2 (size) are not significant.

The orientation and the distribution of the loss contour lines in plot B indicate that the variable x_1 (shape) is not significant. And, the loss surface

raises more precipitously in both sides of the onion size than the one in the efficiency model (notice the density of contour lines) indicating that the variable of x_2 (size) is more significant. In addition, the surface has a little warp, thus, the interaction x_1x_2 (shape and size) is significant. This confirms the results of the analysis of variance. Peeling loss is significantly affected by the onion size (this point will be discussed in more detail later), this may be due to the ends-cutting and slitting mechanism's ability to adopt to a different size onion.

Figure 44 shows the plots for the peeling efficiency and the machine peeling loss models as affected by onion shape and air pressure. Generally, they are two slightly curved planes and are inclined in the same direction in terms of the air pressure. Thereby, it is resulted, first, the air pressure is very significant to both models regardless of the onion shape; second, since the response surfaces are inclined in the same direction in terms of pressure, the possible compromise for a choice which satisfies both models is the medium air pressure. In addition, the F-value of x_3 (pressure) in the model of machine peeling loss is 160.45, which is much higher than the one (39.70) in the efficiency model. This confirms the above analysis that air pressure has a telling on effect to machine peeling loss; second, that machine peeling loss is more sensitive than peeling efficiency to air pressure changes.

It is noted that the machine seems to perform better on the flat-shaped onion than on others. This impression results from the following: the highest value for peeling efficiency is located in the corner (86%) of the flat-shaped onions and at the highest air pressure, while the lowest value

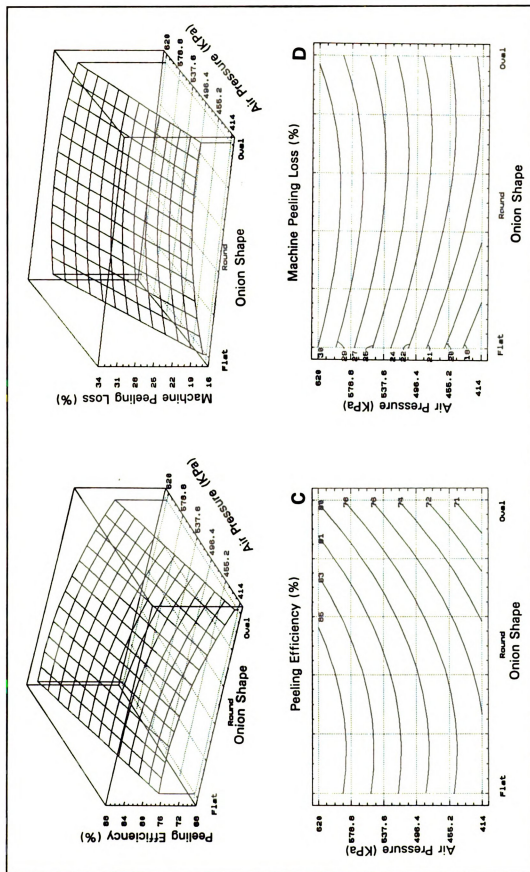


Figure 44 The response surface and contour plots of peeling efficiency and machine peeling loss as affected by onion shape and air pressure

formachine peeling loss is in the corner (18) of flat shape onion and at the lowest air pressure. This indicates that the machine is more suited to flat shape onions. On the other hand, the lowest value for peeling efficiency is in the corner (71 %) of the oval shape and at low air pressure, the highest value for machine peeling loss is in the area of the oval-and-round-shaped onion and at high air pressure. This indicates that the machine is less suited to the oval shape onions. Furthermore, from contour plots, it is also noted that flat shape onions are better than others for the machine. For instance, for certain air pressure, in plot D, say 537.6 kpa, the oval-and-round-shaped onion has a value of 27% for peeling loss, while for the flat-shaped onion the value is only 25% or lower, and, in plot C, one finds that the oval-shaped onion has a value of 76% for peeling efficiency, while the value for the flat shape onion is 82%. This feeling is confirmed by the analysis of variance. In the loss model the interaction of x_1x_3 (shape and pressure) is significant at the level of 0.05, and the second order of x_1 (shape) is significant for both models.

By further examining the surface and contour plots one finds that the optimal value for peeling efficiency is located in the area between the flat and the round shape with medium and high air pressure. For peeling loss the minimum value is located in the area between the flat and the roundshape with medium and low air pressure. Consequently, the possible optimal area for satisfying both models is between flat and round shape onion with a medium air pressure.

Figure 45 shows the plots for the peeling efficiency and the machine peeling loss models as affected by onion shape and chain speed. Both

response surfaces appear a little warped. They are diagonally inclined in a similar direction, that is, their lowest values are located in the same area, namely, the oval shape and the high speed area. But their highest values are located in different areas. The highest value for peeling efficiency is located in the region of the low speed regardless of onion shape, while the highest peeling efficiency and machine peeling loss as affected by onion shape and chain speed value for peeling loss is located in the corner of the low speed but oval shape.

There are two practical inferences that could be drawn from above observation. First, speed has an inverse effect to peeling efficiency, that is, higher speed causes lower peeling efficiency, particularly for round- and oval- shaped onions. When speed exceeds 84 onions/min, peeling efficiency worsens quickly. Therefore, in practice, one should avoid operating in this area. However, in the same area opposite happens to peeling loss, that is, when the speed is higher than 84 onion/min. the peeling loss getting down. Consequently, the possible compromise for a choice which satisfies both models can be found only in the area around medium speed. If the speed is too high, it will result in low peeling efficiency even though we would get higher peeling capacity and lower peeling loss. If the speed is too low it will cause high peeling loss and low peeling capacity even though we could get higher peeling efficiency. Speed significantly affects the response models, which is also confirmed by the results of the analysis of variance. It is significant at a level of 0.01 or higher for both models. Therefore, this investigation suggests keeping medium or a slight high speed to fulfill both models.

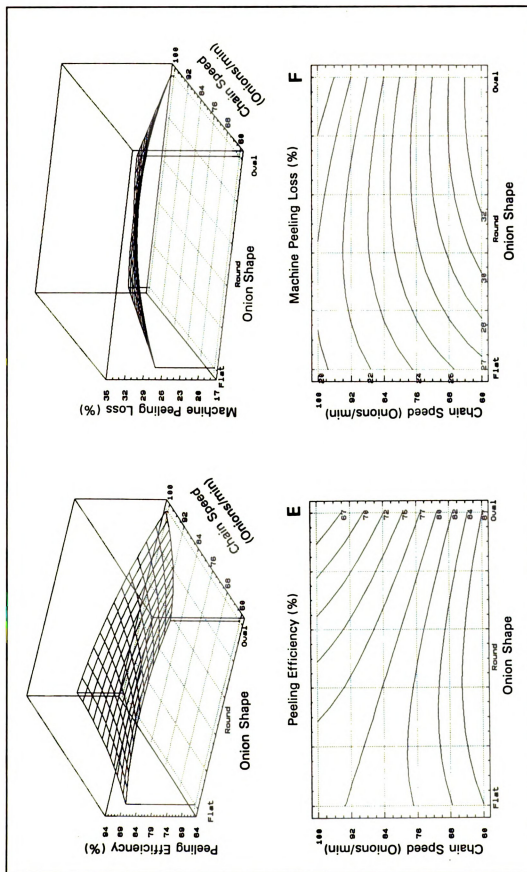


Figure 45 The response surface and contour plots of peeling efficiency and machine peeling loss as affected by onion shape and chain speed

Second, the analysis of Figure 43 and Figure 44, is confirmed, that in general, oval-shaped onions have higher peeling loss than flat-shaped onions for all speeds, pressures and sizes. The effect of onion shape is mainly caused by the interaction, x_1x_4 (shape and speed), and its second order, x_1^2 . Even though its first order x_1 is eliminated from the estimated equations. Furthermore, the efficiency surface is warped in a diagonal direction, the possible optimal efficiency should locate in the area nearby the straight line of 80% in the contour plot of the peeling efficiency model.

The fact that oval-shaped onions have higher peeling loss and lower peeling efficiency and flat-shape onions have lower peeling loss and higher peeling efficiency may be explained by the following: (1) more top and root portions are cut in the case of oval-shaped onions; (2) the cut portions mentioned above are no help for increasing the peeling efficiency; (3) the slitting is not sufficient as in the case of flat shape onions.

Figure 46 shows the plots for the peeling efficiency and machine peeling loss models as affected by onion size and air pressure. The response surfaces are two curved surfaces and are inclined in the same direction in terms of pressure. The inclination indicates the compressed air jet system is highly effective to both models. The curvature of the surfaces indicates the interaction, x_2x_3 (size and pressure) is significant to both models. And, it is noted from the plots that the hollow of the surfaces were shifted slightly to the right of the medium size, which is caused by the effect of onion size.

By comparing two surfaces, one finds that the loss surface is curvier than the surface of efficiency, which indicates that the loss model is more

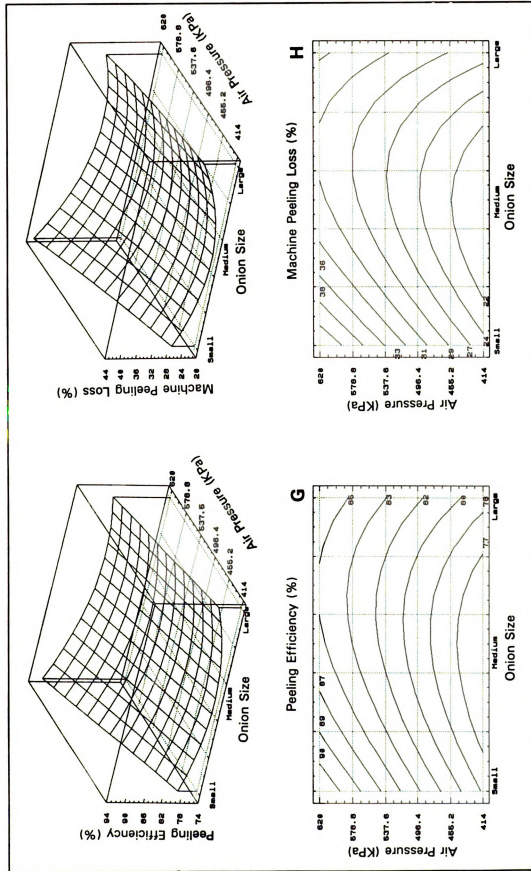


Figure 46 The response surface and contour plots of peeling efficiency and machine peeling loss as affected by onion size and air pressure

sensitive than the efficiency model to size change. This confirms the result of the analysis of variance, that the former has much higher F-value (11.80) than the later (1.92). The two surfaces are inclined in terms of pressure. This also confirms that the result of the analysis of variance, x_3 (pressure) was significant at a 0.01 level or higher for both models. Comparing the curvature and the distribution of the contour lines in plots H and G, it is noted that the effect of onion size and/or air pressure in the loss model is more significant than in the efficiency model. This was confirmed by the results of the analysis of variance, i.e., x_2 (size), x_3 (pressure) and x_2x_3 (size and pressure) are more significant in the loss model than in the efficiency model.

From surface and contour plots one can see that the feasible limited value (minimum) for both peeling loss and peeling efficiency models in terms of size is located in the area between medium and large. Thereby, the feasible optimum size which satisfies both models is between medium and large onions, i.e., 87 mm in detail.

Figure 47 shows the plots for the peeling efficiency and the machine peeling loss models as affected by onion size and chain speed. The surfaces are backward inclined in the same direction in terms of speed, and the surfaces have the similar features with the case discussed in Figure 46. The inclination of the surfaces is caused by the speed. The curvature of the surfaces is mainly determined by the effect of the interaction, x_2x_4 , but in this case, the influence of the interactions to the models are much weaker, particularly in the model of peeling loss. And, also, the hollow of the surfaces were shifted slightly to the right of the medium size. All above

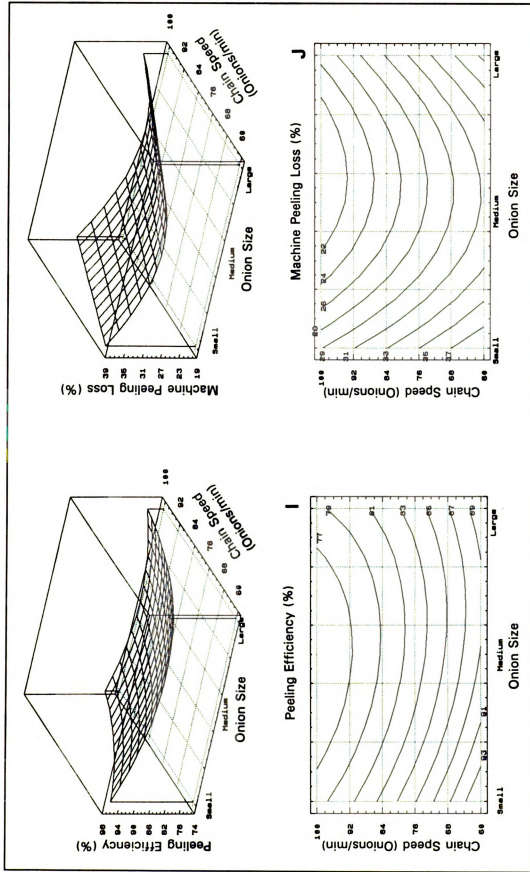


Figure 47 The response surface and contour plots of peeling efficiency and machine peeling loss as affected by onion size and chain speed

observations are confirmed by the results of the analysis of variance.

From contour plots one can see that the possible limited value in terms of size for both models is located in the area between medium and large. That the contour lines in the peeling loss model appear much curvier than the one in efficiency model indicates that loss model more sensitive to the size change. This also confirms the result of the analysis of variance, that is, that the size is significant at level of 0.05 for the loss model, while it is not significant for the efficiency model.

Figure 48 shows the plots for the peeling efficiency and the machine peeling loss as affected by air pressure and chain speed. The response surfaces are similarly diagonally-inclined planes and are sloped in the same direction in terms of the interaction of x_3x_4 (pressure and speed). Their highest response values are located in the same corner of the high pressure and the low speed; and their lowest values are located in the same corner of the low pressure and the high speed.

From the contour plot of the efficiency model one can see that it is a curved surface, which indicates that the model is affected by the interaction, x_3x_4 (pressure and speed). This feature is confirmed by the results of the variance, in which x_3x_4 was found to be significant at a level of 0.05, whereas, the surface of the peeling loss model is a flat plane, and all contours are straight lines. This feature is also confirmed by the results of the analysis of variance for the loss model, in which x_3x_4 was not significant.

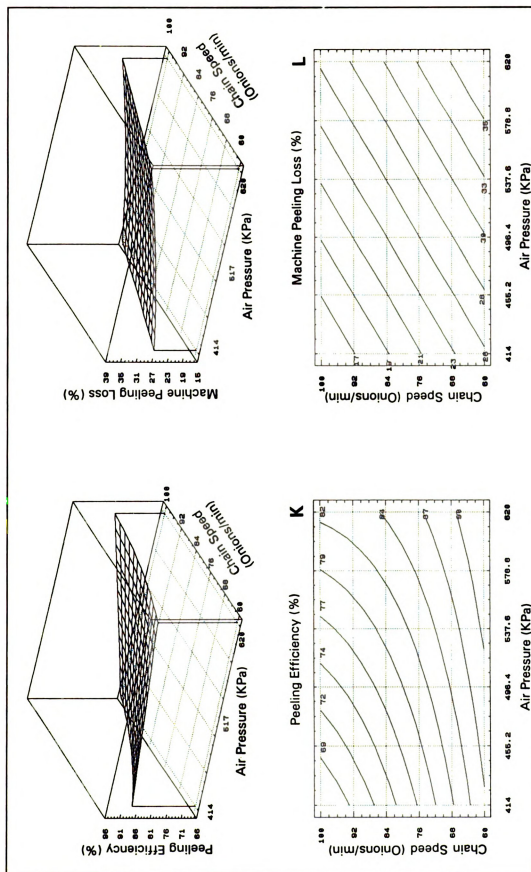


Figure 48 The response surface and contour plots of peeling efficiency and machine peeling loss as affected by air pressure and chain speed

4.4.4 Response Surface Analysis

One of the objectives of this study was to find a set of operating conditions which could optimize the responses, namely, to search a set of values from chain speed, air pressure, onion shape, and onion size which could maximize peeling efficiency and minimize machine peeling loss. Practice and experiments indicated that peeling efficiency and machine peeling loss are two mutually conditioned responses. They are both opposite and complementary to each other. Therefore, this is a multiple response problem. The computer generated second order polynomial equations, as shown in Eq. 4.5 and Eq. 4.6, were used as empirical models for searching the optimum in the experimental region. Peeling capacity response was considered as chain speed in the optimal analysis.

The optimal condition searching procedure consisted of: (1) calculating the stationary points (points of zero slope or points where the first derivative is zero); (2) performing a canonical analysis, and (3) superimposing corresponding contour plots.

The method of calculating stationary points was introduced in detail by Myers (1971) and Draper (1963). In this study, MATHEMATICA (1991) was used to calculate the stationary points and find the characteristic root of the B-matrix for building canonical forms. The stationary points are presented in Table 10. Something can be learned from the stationary points. In the model of peeling efficiency, the stationary point indicates that the optimal onion shape is between oval and round, and just short of round. The optimal size is 100 mm. The air pressure is 1000 kpa. The chain speed is 56 onions/min. In the peeling loss model, the stationary point indicates

Table 10
Stationary Points for Response Models

Variables	Coded Experimental Region	Stationary Points	
		Efficiency	Loss
Onion Shape	from -1 to 1	0.698	- 1.476
Onion Size	from -1 to 1	1.349	-0.609
Air Pressure	from -1 to 1	4.658	-5.328
Chain Speed	from -1 to 1	- 1.243	3.988

that the optimal onion shape is flat. The optimal size is 76 mm. The air pressure is 0 kpa. The chain speed is 160 onions/min. The values of shape and size still remain in the experimental region, but, speed and pressure are totally outside it. Particularly, the pressure in the two models seems antithetical to each other. Subsequently, it is noted that in both cases, the four-dimensional stationary points are located outside the experimental region. Therefore, from the point of view of practical feasibility, it is necessary to move away from these points and to locate the optimum inside the experimental region.

Two B-matrices can be obtained from the estimated quadratic polynomial equations. They are as following:

Peeling efficiency B-matrix

$$\begin{bmatrix} -2.49815 - \lambda & 0.32917 & -0.25139 & -1.80139 \\ 0.32917 & 3.67963 - \lambda & -0.80417 & 0.69167 \\ 0.25139 & -0.80417 & 0.04630 - \lambda & 1.30556 \\ -1.80139 & 0.69167 & 1.30556 & 1.63519 - \lambda \end{bmatrix} = 0$$

Peeling loss B-matrix

$$\begin{bmatrix} -1.65926 - \lambda & 0.51945 & 0.56389 & -1.23056 \\ 0.51945 & 6.55185 - \lambda & -1.36667 & -0.43477 \\ 0.56389 & -1.36667 & 0.78519 - \lambda & -0.10278 \\ -1.23056 & -0.434722 & -0.102778 & 0.04074 - \lambda \end{bmatrix} = 0$$

Expanding the determinants and solving the two quartic equations yields the characteristic roots of the B-matrix. Then, the canonical form results in the following equations for peeling efficiency and machine peeling loss.

$$\hat{Y}_E = 96.6 - 3.25 W_1^2 - 0.72 W_2^2 + 2.89 W_3^2 + 3.94 W_4^2$$

$$\hat{Y}_{ml} = -1.55 - 2.40 W_1^2 + 0.13 W_2^2 + 1.08 W_3^2 + 6.91 W_4^2$$

Where,

W_1 , W_2 , W_3 , and W_4 (eigenvalues or coefficients) are linear

combinations of the x_i .

From the equations, it is noted that the characteristic roots (eigenvalues or coefficients) have mixed signs. This indicates that the stationary points exist in terms of saddle points, which in turn suggests that movement away from these points would cause an increased or decreased response, depending upon the direction of the movement (Myers, 1971).

The location of the stationary points as well as the form of the canonical equations suggest that a complicated ridge system exists for both of the response surfaces. Analysis of such a ridge system is not easy to

perform and is not always successful, especially when multi-response problems are involved in the system (Floros and Chinnan, 1987). Hence, a simpler approach, computer graphical superimposition approach, was taken to further explore and explain the system. A series of contour plots of equal response were generated by computer which provide useful information for further investigation.

4.4.5 Graphical Approach

In the graphical approach, the estimated models were used to create superimposed contour plots within the experimental region by the computer. The superimposed contour plots are usually generated on two-coordinate diagrams. These plots present information for two factors and one or more responses and are reasonably accurate (depending upon the representational accuracy of the model) within the experimental region. The regions of optimum response(s) are judged by visual inspection to the superimposed contour plots. This method reduces the possibilities of "unrealistic" solutions, since the regions within the experimental space are examined, and allows simultaneous optimization of several competing responses by simple superimposition. Therefore, this method particularly suits the situations in which optimal conditions are searched in a multi-response system and the stationary points are outside the experimental region.

Numerous successful applications of graphical optimization pertaining to mechanical and food systems were reported in the literature (Kissell, 1967; Kissell and Marshall, 1962; Floros and Chinnan, 1987, 1988; Johnson and Zabik, 1981; Lind, Goldin and Hickman, 1960; Henselman et al., 1977;

Myers, 1985; Oh, Seib and Chung, 1985; Terhune, 1963; Underwood, 1962; Wilson and Donelson, 1964; Wu, 1964; Wu and Meyer, 1964).

In this study, the optimization of peeling efficiency and machine peeling loss was realized by superimposing a series of computer generated contour plots. The procedure of superimposition was performed in three sequential steps.

First Step: In the first step, as shown in Figures 43 through 48, two response surfaces and their contour plots were presented in terms of independent variables with six different combinations. They explored the MSU machine peeling system with two variables at a time and showed the responses of peeling efficiency and machine peeling loss separately. A general interpretation was taken to the graphics in section 4.4.3.

Second Step: In order to analyze the two response models simultaneously and to find a set of operational conditions satisfying both models, in the second step, two corresponding contour plots in terms of peeling efficiency and machine peeling loss were superimposed on each other from Figures 43 through 48. The results are shown in Figure 49-A through 49-C.

Figure 49-A is the superimposition of shape vs. size as well as pressure vs. speed. The shaded area in plot M of Figure 49-A indicates the region of onion shape and onion size in which the peeling efficiency is between 80% and 81%, and the machine peeling loss is between 25% and 27%. The shaded area in Plot R shows the region of air pressure and chain speed in which the peeling efficiency is between 79% and 82%, and the

machine peeling loss is between 23% and 26%.

Figure 49-B is the superimposition of shape and size vs. speed, respectively. The shaded area in plot O is the region of onion shape and chain speed in which the peeling efficiency is between 80% and 82%, and the machine peeling loss is between 24% and 25%. The shaded area in plot Q shows the region of onion size and chain speed in which the peeling efficiency is between 79% and 81%, and the peeling loss is between 24% and 26%.

Similarly, in Figure 49-C, the shaded areas in plot N is the region of onion shape and air pressure in which the peeling efficiency is between 80% and 81%, and the peeling loss is between 25% and 27%. In plot P, the shaded area shows the region of onion size and air pressure in which the peeling efficiency is between 80% and 82%, and the peeling loss is between 24% and 27%.

Third Step: In the third step, contour plots in terms of speed and pressure were further superimposed by computer from O and Q in Figures 49-B for speed and from N and P in Figure 49-C for pressure. The results are shown as S in Figure 49-B and as T in Figure 49-C. In these plots, S and T, the immaterial contour lines were eliminated for clarity, the small cross-shaded areas show the region of optimal feeding chain speed and air pressure which satisfies the conditions of the peeling efficiency being about 80% and the peeling loss being about 25%. It is noted from plot S in Figure 49-B, the optimal chain speed is around 84 onions/min., the optimal onion shape is between flat and round shape, and just short of round. From plot T in Figure 49-C, the optimal air pressure can be found in the region

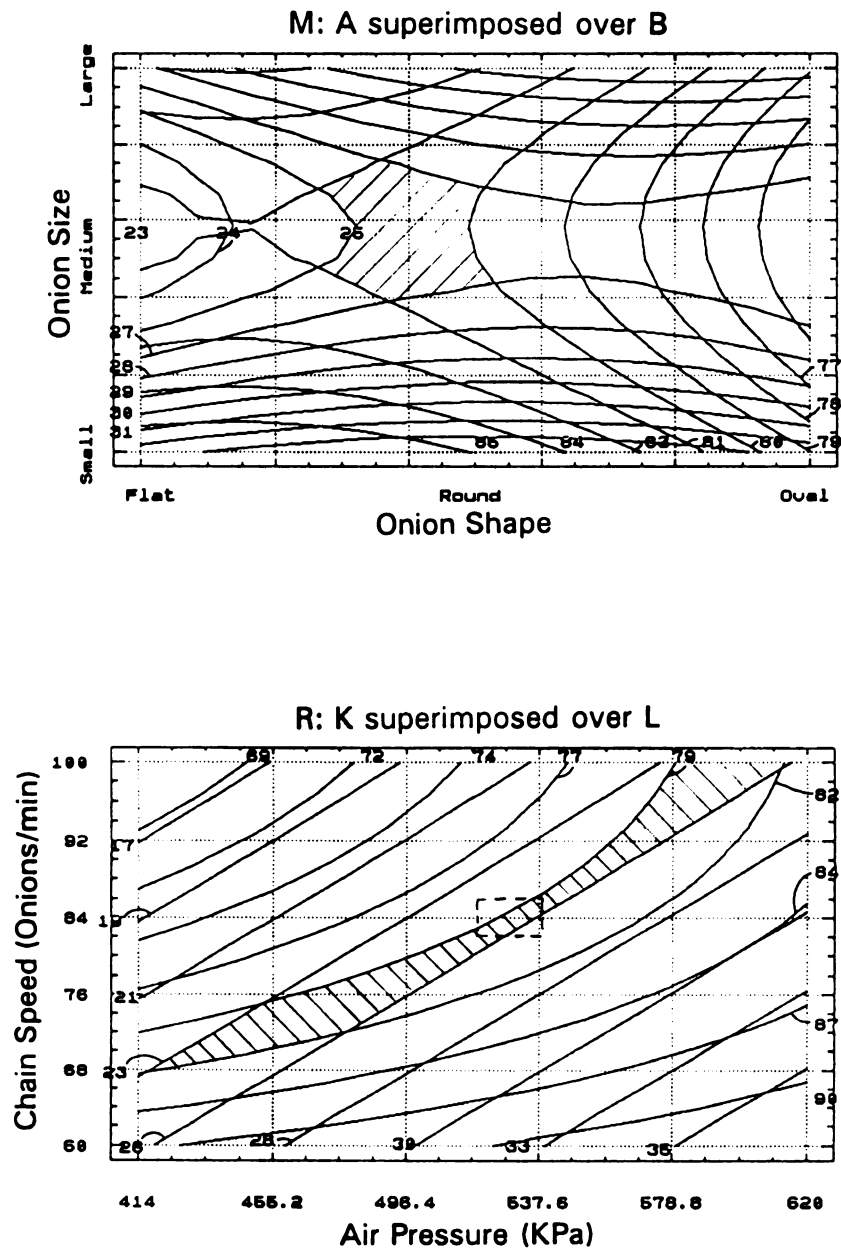


Figure 49-A Superimposed contour plots for two response models

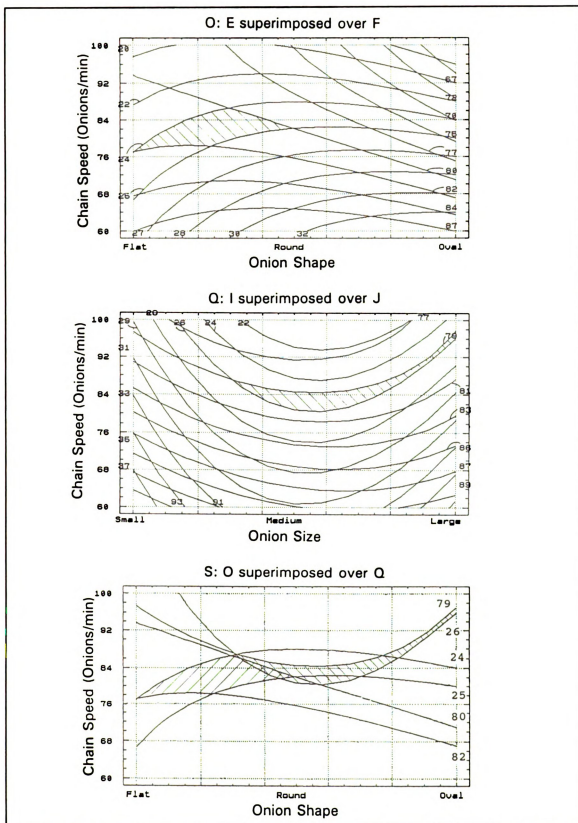


Figure 49-B Superimposed contour plots for two response models

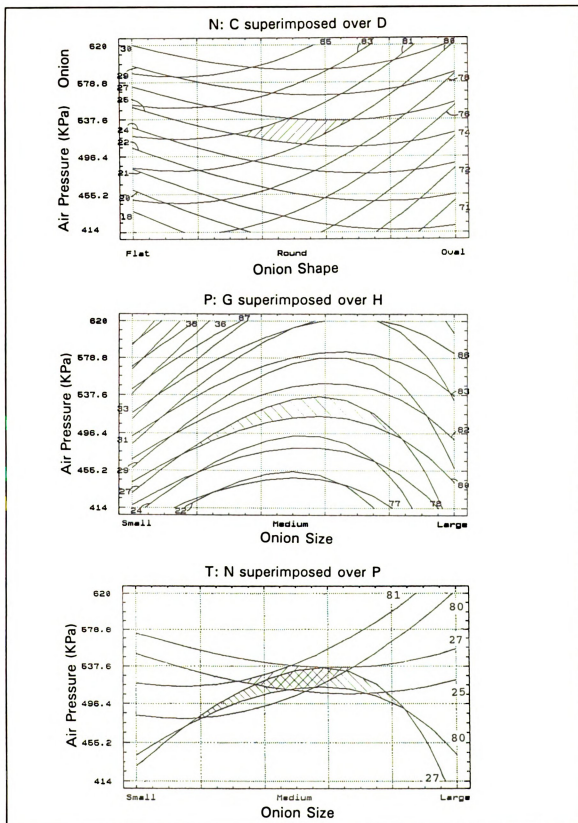


Figure 49-C Superimposed contour plots for two response models

between 517 kpa and 537.6 kpa and the optimal onion size is medium.

This conclusion can be verified from plot M and R in Figure 49-A. In plot M, the small square represents the region of the optimal shape and size obtained from the plots S and T in Figure 49-B and C, it is just located in the shaded area of plot M in Figure 49-A. In plot R of Figure 49-A, the small square represents the region of the optimal pressure and speed obtained from the plots S and T in Figure 49-B and C, it is overlapped on the shaded area of plot R in Figure 49-A.

According to the above conclusion, at the speed of 84 onions/min for round and medium size onion, the optimal peeling capacity for the machine is computed as 756 Kg/h.

The Hoke D_6 design (Hoke, 1974) meets the Wheeler (1972) criteria and has high efficiencies. Its economical feature particularly suits research that includes independent variables greater than three, and, therefore, was suggested by Thompson (1982) and Lucas (1976). In this experiment, only 19 experimental runs were required to obtain the highest value of coefficient of multiple determination (R^2). The value of R^2 of the Hoke D_6 design was 0.88 for peeling efficiency and 0.94 for machine peeling loss, respectively. The general conclusion of the Hoke D_6 design was the same as the factorial design. But, in some aspects, the Hoke D_6 design resulted in a better conclusion than did the complete factorial design. For example, the optimal chain speed of 84 onions/min obtained from the Hoke D_6 design, resulted in a peeling loss of lower than 24% combined with a peeling efficiency of higher than 86%. This value (optimal speed) was more precise than the one obtained in the factorial design. More detailed information can be found

in Appendix B. One suspects there may be a possible disadvantage is that there is the bias due to the existence of higher order terms. However, for this four factors design it should not be a problem. But, as a preliminary investigation using only 19 points, finding 15 parameters and 2 responses seems too weak to support the conclusion.

The Box-Behnken design was also tried for the analysis of variance. The advantage of the design is that it needs only a total of 27 runs and the lack of fit can be tested by adding only two extra central points. The analysis of the fitting-test indicated that the lack of fit was not significant at 5% for both models of machine peeling loss and peeling efficiency. The R^2 values were 0.69 for the peeling efficiency model and 0.88 for the machine peeling loss model, respectively. The experiment layout and the results of analysis of variance by the Box-Behnken design are presented in Appendix C.

CHAPTER V

SUMMARY AND CONCLUSIONS

5.1 Summary

In this study, the MSU second prototype onion peeling machine and its performance were evaluated qualitatively and quantitatively.

In the qualitative evaluation, the background of onions' economic significance as well as their products and manufacturing methods were reviewed; onion peeling methods and equipments which were granted U.S. Patents in the last 100 years (1890-1990) were investigated and summarized; and the applications of the Response Surface Methodology in mechanical systems and food engineering were selectively presented. Based upon the above information, the technology process and the construction of the MSU onion peeling machine were evaluated.

The MSU machine is farm level onion peeling machine. It was designed to peel pungent Michigan onions and performs an eight stage classical peeling technology in a manner of continuous flow. The machine consists of six major mechanical systems. It applies a novel approach of using four scoring blades assisted by compressed air jets to make four mutual perpendicular slits in the outer layers of the onion skin. The

compressed air penetrates through the slits and causes the skins to loosen and/or dislodge from the onion bulb. A pair of parallel blades rotating at a high speed trim the ends of the onion. A pair of Co-rotating rollers assisted by three compressed air nozzles are utilized to spin the scored and trimmed onions for final separation and removal of the onion peels.

In the quantitative evaluation, the machine performance was characterized by peeling efficiency, machine peeling loss and peeling capacity. Onion shape, onion size, air pressure and chain speed were investigated as major factors influencing the machine's performance. Two sequential statistical experiments were taken to the MSU onion peeling machine. Three types of Response Surface Design (Hoke D_6 , Bos-Behnken and factorial) were conducted to test the machine's performance and properties. Two second order polynomial equations were created and modified by computer as the empirical models to simulate the performance characteristics (peeling efficiency and machine peeling loss) and their explanatory variables (shape, size, pressure and speed). Computer generated response surfaces and contour plots as well as the analysis of variance were used to analyze the machine's performance. In addition, canonical analysis was applied in judging the location of stationary points. Because searching for a maximum peeling efficiency and minimum peeling loss is a multi-response problem, and also, the stationary points were outside the experimental region, consequently, a computer graphical superimposing method was used to locate the optimal operating condition in the experimental region. The obtained optimum satisfies both of the models of machine peeling loss and peeling efficiency simultaneously .

5.2 Conclusions

The results of machine performance testing and statistical analysis indicated that the MSU machine is an efficient onion peeling machine. For round shape and medium size (82.5 mm) pungent Machine onions, the peeling efficiency of 80% or higher is obtainable while keeping the machine peeling loss as low as 25%, and an average peeling capacity of 576 kg/h or higher is possible.

The results of the experiment also indicated that the air pressure, the feeding chain speed and the interaction of onion shape and feeding chain speed are highly significant for both models of peeling efficiency and machine peeling loss. The onion size as well as the interaction of onion size and air pressure significantly affected the model of machine peeling loss, whereas the interaction of air pressure and feeding chain speed is significant to the model of peeling efficiency.

Because the MSU onion peeling machine possesses compact construction, reliable conveying and holding system, passive performing components and full hydraulic power and control system as well as performing successive flow processing procedure, it also is a safe and economical farm onion peeling machine. Particularly, the application of the novel air jet nozzles greatly increases the peeling efficiency. The self-regulating technique relevantly applied in the machine system greatly enhances the peeling adaptability.

CHAPTER VI

RECOMMENDATIONS FOR FURTHER RESEARCH

(1) The adequacy of the model equations should be examined in the onion peeling plant.

(2) If new experimentation needs to be conducted for the machine, the replications should be taken to each testing point.

(3) It would be valuable to see if grading onions in size first then feeding them to the machine with different chain speeds will decrease the machine peeling loss.

(4) It would be also valuable to test whether the graded-onion helps to improve the feeding or loading quality, thereby increasing the peeling efficiency and decreasing the machine peeling loss.

(5) If the moisture and the storage time can be considered as factors in an experiment, it would be helpful to discover their influence on the peeling efficiency, and, in turn, it would be profitable to handle the pre-processing conditions in onion peeling.

APPENDICES

APPENDIX A

MSU Onion Peeling Machine First Experiment

The ANOVA Table and The Raw Data

Table A.1

**The First Experiment: The ANOVA Table for The Peeling Efficiency
(Air Pressure = 75 psi)**

Effect	d.f.	SS	MS	F
Total (corr.)	8	1381.6290		
x_1 : Chain Speed	1	900.37500	900.37500	91.91 **
x_2 : Onion Size	1	11.20667	11.20667	1.14
x_1x_2	1	14.06250	14.06250	1.44
x_1^2	1	204.69390	204.69389	20.90 **
x_2^2	1	221.90222	221.90222	22.65 **
Total Error	3	29.38861	9.79620	

$$R^2 = 0.978729$$

** Significant at the 0.05 level.

$$R^2 \text{ (adj. for d.f.)} = 0.943277$$

Table A.2

**The First Experiment: The ANOVA Table for The Total Peeling Loss
(Air Pressure = 75 psi)**

Effect	d.f.	SS	MS	F
Total (corr.)	8	104.16000		
x_1 : Chain Speed	1	4.166667	4.166667	1.67
x_2 : Onion Size	1	42.135000	42.135000	16.89 **
x_1x_2	1	44.890000	44.890000	18.00 **
x_1^2	1	1.2800000	1.280000	0.51
x_2^2	1	4.2050000	4.205000	1.69
Total Error	3	2.4944440	2.494444	

$$R^2 = 0.928155$$

** Significant at the 0.05 level.

$$R^2 \text{ (adj. for d.f.)} = 0.808414$$

Table A.3

**The First Experiment:
The Experiment Latout and The Raw Data Table**

Run	Size	Speed	Pressure	W_i	W_m	W_f	E	W_L
1	L	M	M	25.4	20.8	17.0	55	33.0
2	M	M	M	34.6	26.2	21.0	62	39.3
3	S	M	M	27.2	21.8	18.4	61	32.4
4	M	S	M	43.6	30.6	28.4	86	34.9
5	M	M	M	36.4	28.6	22.4	56	38.5
6	S	S	M	44.0	30.0	25.4	82	42.3
7	M	M	L	38.4	30.4	25.4	62	33.9
8	M	M	H	41.2	31.6	25.0	59	39.3
9	L	S	M	29.0	20.6	18.6	81	35.9
10	S	S	M	27.2	20.0	18.4	75	32.4
11	M	F	M	41.4	31.6	26.8	67	35.3
12	L	F	M	37.4	29.0	20.6	50	44.9
13	S	F	L	28.2	25.8	19.4	27	31.2

Notes: Onion Size

S: Small = 70 mm

M: Medium = 82.5 mm

L: Large = 95 mm

Air Pressure

L: Low = 65 psi

M: Medium = 75 psi

H: High = 85 psi

Chain Speed

S: Slow = 10 M/min

M: Medium = 13 M/min

F: Fast = 24 M/min

APPENDIX B

The MSU Onion Peeling Machine Second Experiment The Hoke D₆ Design The Design Layout and The ANOVA Table

Table B.1
The Second Experiment: The Experiment Layout and Raw Data
Table of The Hoke D₆ Design

Run	Shape	Size	Pressure	Speed	Machine Loss	Efficiency
1	-1	0	0	0	23.4	66.7
2	0	-1	0	0	39.6	93.3
3	0	0	-1	0	21.2	87.8
4	0	0	0	-1	27.1	95.8
5	-1	-1	-1	-1	28.3	72.2
6	-1	1	1	1	26.3	79.0
7	1	-1	1	1	27.9	77.3
8	1	1	-1	1	17.5	68.6
9	1	1	1	-1	44.3	91.2
10	1	1	-1	-1	33.3	88.2
11	1	-1	1	-1	45.2	96.6
12	1	-1	-1	1	19.4	60.0
13	-1	1	1	-1	40.7	90.6
14	-1	1	-1	1	20.9	70.6
15	-1	-1	1	1	44.6	89.1
16	0	1	1	1	28.2	84.1
17	1	0	1	1	21.9	77.8
18	1	1	0	1	24.3	81.0
19	1	1	1	0	27.0	82.2

Table B.2
The Second Experiment: The ANOVA Table for The Peeling Efficiency (Hoke D₆ design)

Effect	SS	DF	MS	F	P
x₁: Pressure	638.209991	1	638.209991	25.56	0.0003
x₄: Speed	603.107646	1	603.107646	24.16	0.0004
x₁x₂	26.333999	1	26.333999	1.05	0.3247
x₂x₃	241.942343	1	241.942343	9.69	0.0090
x₁²	510.316822	1	510.316822	20.44	0.0007
x₂²	62.468149	1	62.468149	2.50	0.1397
Total error	299.606673	12	24.96722		
Total (corr.)	1988.37789	18			
R² = 0.849		R_a² = 0.774			

Table B.3
The Second Experiment: The ANOVA Table for The Machine Peeling Loss (Hoke D₆ design)

Effect	SS	DF	MS	F	P
x₁: Shape	41.599238	1	41.599238	2.76	0.1407
x₂: Size	70.289409	1	70.289409	4.66	0.0677
x₁: Pressure	372.488433	1	372.488433	24.70	0.0016
x₄: Speed	200.746235	1	200.746235	13.31	0.0082
x₁x₂	47.054408	1	47.054408	3.12	0.1207
x₁x₄	32.437576	1	32.437576	2.15	0.1859
x₂x₃	37.053878	1	37.053878	2.46	0.1610
x₂x₄	41.923738	1	41.923738	2.78	0.1394
x₃x₄	30.012514	1	30.012514	1.99	0.2012
x₁²	29.552949	1	29.552949	1.96	0.2043
x₂²	193.223458	1	193.223458	12.81	0.0090
Total error	105.554954	7	15.07928		
Total (corr.)	1474.22105	18			
R² = 0.928		R_a² = 0.816			

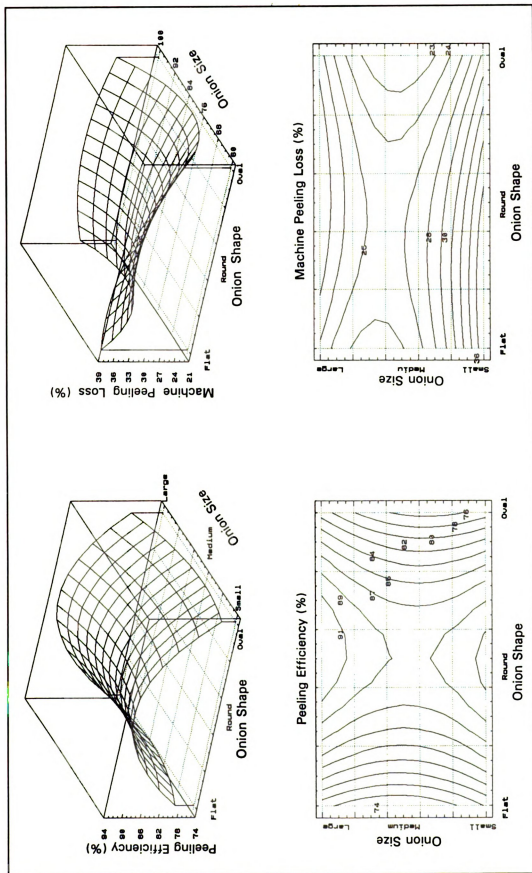


Figure B-1 The response surface and contour plots of peeling efficiency and machine peeling loss as affected by onion shape and onion size in the Hoke D_6 design

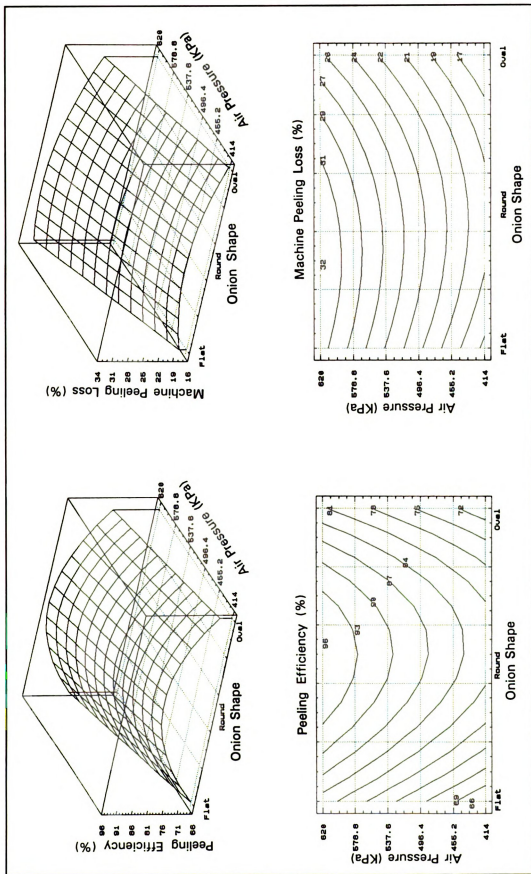


Figure B-2 The response surface and contour plots of peeling efficiency and machine peeling loss as affected by onion shape and air pressure in the Hoke D_6 design

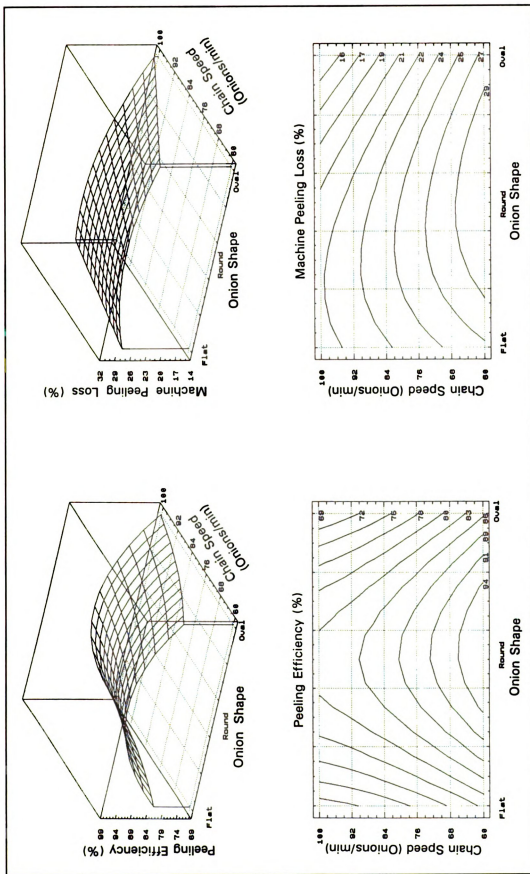


Figure B-3 The response surface and contour plots of peeling efficiency and machine peeling loss as affected by onion shape and chain speed in the Hoke D₆ design

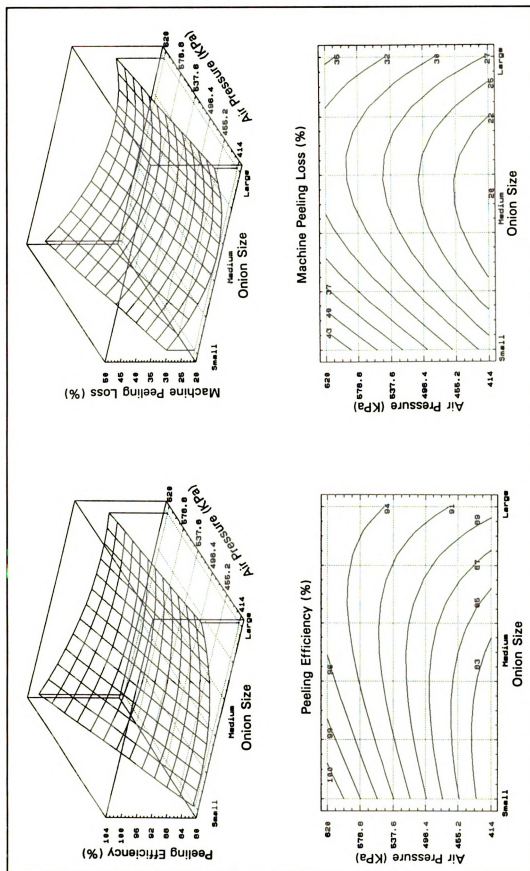


Figure B-4 The response surface and contour plots of peeling efficiency and machine peeling loss as affected by onion size and air pressure in the Hoke D₆ design

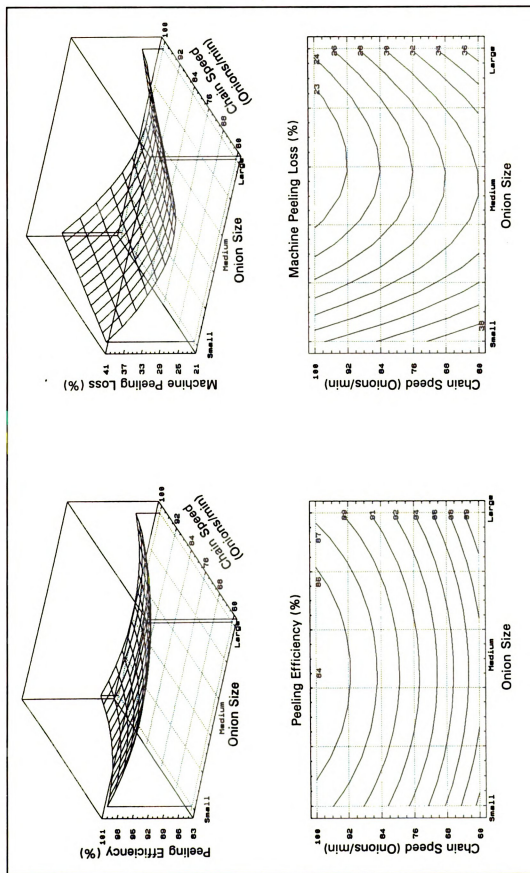


Figure B-5 The response surface and contour plots of peeling efficiency and machine peeling loss as affected by onion size and chain speed in the hoke D_6 design

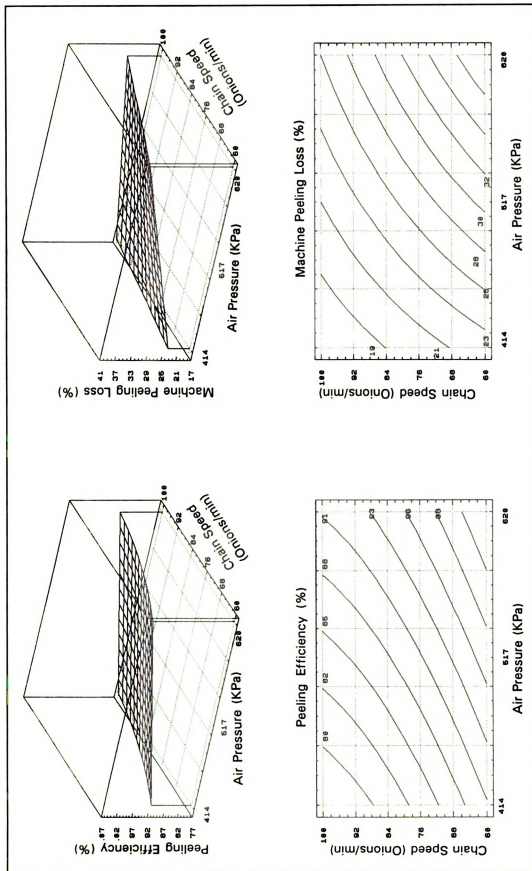


Figure B-6 The response surface and contour plots of peeling efficiency and machine peeling loss as affected by air pressure and chain speed in the Hoke D₆ design

APPENDIX C

The MSU Onion Peeling Machine Second Experiment The Box-Behnken Design The Experiment Layout and The ANOVA Table

Table C.1
The Second Experiment: The Experiment Layout and The Raw Data
Table of The Box-Behnken Design

Run	Shape	Size	Pressure	Speed	Machine Loss	Efficiency
1	0	0	0	0	22.5	91.7
2	-1	0	1	0	29.6	77.4
3	0	-1	-1	0	28.3	83.3
4	1	0	-1	0	23.3	72.4
5	0	0	1	-1	37.7	94.1
6	0	1	0	-1	37.9	82.0
7	-1	0	0	-1	33.3	89.3
8	1	1	0	0	29.4	69.6
9	0	1	0	1	23.2	82.9
10	-1	0	-1	0	19.5	79.0
11	0	-1	0	1	20.8	68.8
12	-1	1	0	0	26.5	71.1
13	-1	0	0	1	21.9	72.7
14	0	0	0	0	23.7	67.0
15	0	-1	0	-1	41.1	100.0
16	1	0	0	-1	37.0	90.2
17	1	0	0	1	18.3	61.3
18	1	-1	0	0	26.2	84.2
19	0	1	-1	0	31.0	81.6
20	1	0	1	0	21.1	75.8
21	0	0	-1	-1	23.5	83.3
22	-1	-1	0	0	32.6	85.7
23	0	1	1	0	35.1	88.5
24	0	0	1	1	27.4	85.2
25	0	0	-1	1	16.7	53.9
26	0	-1	1	0	41.7	83.3
27	0	0	0	0	24.3	62.0

Table C.2
The Second Experiment: The ANOVA Table for The Peeling Efficiency (Box-Behnken design)

Effect	SS	DF	MS	F	P
x_1 ; Shape	39.2408	1	39.2408	0.16	0.7354
x_2 ; Size	73.0133	1	73.0133	0.29	0.6499
x_3 ; Pressure	215.0533	1	215.0533	0.85	0.4625
x_4 ; Speed	1084.9008	1	1084.9008	4.29	0.1741
x_1x_4	37.8225	1	37.8225	0.15	0.7399
x_2x_4	257.6025	1	257.6025	1.02	0.4191
x_3x_4	105.0625	1	105.0625	0.42	0.5914
x_2^2	230.3301	1	230.3301	0.91	0.4496
x_3^2	65.1751	1	65.1751	0.26	0.6669
x_4^2	97.6067	1	97.6067	0.39	0.6037
Lack-of-fit	476.9758	14	34.0697	0.13	0.9937
Pure error	505.7267	2	252.8633		
Total (corr.)	3075.64667	26			
$R^2 = 0.858$			$R_a^2 = 0.597$		

Table C.3
The Second Experiment: The ANOVA Table for The Machine Peeling Loss
(Box-Behnken design)

Effect	SS	DF	MS	F	P
x_1 : Shape	5.46750	1	5.46750	6.51	0.1254
x_3 : Pressure	210.84083	1	210.84083	251.00	0.0040
x_4 : Speed	563.07000	1	563.07000	670.32	0.0015
x_1x_2	21.62250	1	21.62250	25.74	0.0367
x_1x_3	37.82250	1	37.82250	45.03	0.0215
x_1x_4	13.32250	1	13.32250	15.86	0.0577
x_2x_3	21.62250	1	21.62250	25.74	0.0367
x_2x_4	7.84000	1	7.84000	9.33	0.0925
x_2^2	264.33844	1	264.33844	314.69	0.0032
x_3^2	18.90375	1	18.90375	22.50	0.0417
x_4^2	30.71344	1	30.71344	36.56	0.0263
Lack-of-fit	159.85167	13	12.29628	14.64	0.0657
Pure error	1.68000	2	0.84000		
Total (corr.)	1309.80667	26			
$R^2 = 0.914$			$R_a^2 = 0.748$		

Appendix D

The MSU Onion Peeling Machine Second Experiment The Full Factorial Design The Experiment Layout and The Raw Data Table

Table D.1
The Second Experiment: The Full Factorial Design Layout and The Raw Data Table

Run	Block	Shape	Size	Pressure	Speed	W _i	W _m	W _f	E	W _{ml}
1	1	-1	-1	-1	-1	9.2	6.6	5.6	72.2	28.3
2	1	1	0	-1	-1	20.4	14.6	14.0	90.6	28.4
3	1	0	1	-1	-1	25.8	17.0	16.0	89.8	34.1
10	1	0	-1	0	-1	11.2	6.6	6.6	100.0	41.1
11	1	-1	0	0	-1	15.0	10.0	9.4	89.3	33.3
12	1	1	1	0	-1	28.2	17.4	17.2	98.2	38.3
19	1	1	-1	1	-1	12.4	6.8	6.6	96.6	45.2
20	1	0	0	1	-1	17.0	10.6	10.2	94.1	37.7
21	1	-1	1	1	-1	23.6	14.0	13.0	90.6	40.7
28	1	0	-1	-1	0	10.6	7.6	7.0	83.3	28.3
29	1	-1	0	-1	0	15.4	12.4	11.6	79.0	19.5
30	1	1	1	-1	0	28.2	20.3	18.5	81.4	28.0
37	1	1	-1	0	0	12.2	9.0	8.4	84.2	26.2
38	1	0	0	0	0	16.6	12.2	11.8	91.7	26.5
39	1	-1	1	0	0	24.2	17.8	15.2	71.1	26.5
46	1	-1	-1	1	0	9.6	5.1	4.7	91.8	46.9
47	1	1	0	1	0	19.0	14.0	12.4	75.8	21.1
48	1	0	1	1	0	26.2	17.0	15.8	88.5	35.1
55	1	1	-1	-1	1	12.4	10.0	8.4	60.0	19.4
56	1	0	0	-1	1	16.8	14.0	11.6	53.9	16.7
57	1	-1	1	-1	1	23.0	18.2	16.2	70.6	20.9
64	1	-1	-1	0	1	9.2	6.2	5.6	83.3	32.6
65	1	1	0	0	1	20.8	17.0	14.6	61.3	18.3
66	1	0	1	0	1	25.0	19.2	18.0	82.9	23.2
73	1	0	-1	1	1	10.8	6.3	6.0	93.8	41.7
74	1	-1	0	1	1	15.2	10.6	9.8	85.2	30.3
75	1	1	1	1	1	29.2	21.0	20.2	91.1	28.1

Table D.1 (Cont'd)
The Second Experiment: The Full Factorial Design Layout and The
Raw Data Table

Run	Block	Shape	Size	Pressure	Speed	W_i	W_m	W_f	E	W_{ml}
4	2	0	-1	-1	-1	10.8	7.8	7.4	88.2	27.8
5	2	-1	0	-1	-1	15.4	12.0	10.6	70.8	22.1
6	2	1	1	-1	-1	27.0	18.0	16.8	88.2	33.3
13	2	1	-1	0	-1	12.2	7.2	7.0	96.2	41.0
14	2	0	0	0	-1	17.0	12.4	12.2	95.8	27.1
15	2	-1	1	0	-1	24.0	16.0	15.0	88.9	33.3
22	2	-1	-1	1	-1	9.4	5.0	4.7	93.6	46.8
23	2	1	0	1	-1	18.8	11.8	11.4	94.6	37.2
24	2	0	1	1	-1	26.6	15.4	14.4	91.8	42.1
31	2	1	-1	-1	0	12.0	9.0	8.4	83.8	25.0
32	2	0	0	-1	0	17.0	13.4	12.9	87.8	21.2
33	2	-1	1	-1	0	23.4	17.0	14.8	74.4	27.4
40	2	-1	-1	0	0	9.2	6.2	5.7	85.7	32.6
41	2	1	0	0	0	19.8	15.2	13.4	71.9	23.2
42	2	0	1	0	0	26.8	18.8	16.2	75.5	29.9
49	2	0	-1	1	0	10.8	6.3	5.4	83.3	41.7
50	2	-1	0	1	0	16.2	11.4	10.0	77.4	29.6
51	2	1	1	1	0	27.4	20.0	18.4	82.2	27.0
58	2	-1	-1	-1	1	10.2	8.0	7.2	73.3	21.6
59	2	1	0	-1	1	18.6	16.0	14.2	59.1	14.0
60	2	0	1	-1	1	24.8	20.6	18.8	70.0	16.9
67	2	0	-1	0	1	10.6	8.4	7.4	68.8	20.8
68	2	-1	0	0	1	14.6	11.4	10.2	72.7	21.9
69	2	1	1	0	1	28.0	21.2	19.6	81.0	24.3
76	2	1	-1	1	1	12.2	8.8	7.8	77.3	27.9
77	2	0	0	1	1	16.8	12.2	11.4	85.2	27.4
78	2	-1	1	1	1	22.8	16.8	15.2	79.0	26.3

Table D.1 (Cont'd)
The Second Experiment: The Full Factorial Design Layout and the Raw Data Table

Run	Block	Shape	Size	Pressure	Speed	W_i	W_m	W_f	E	W_{ml}
7	3	1	-1	-1	-1	12.2	8.8	8.6	94.4	27.9
8	3	0	0	-1	-1	17.0	13.0	12.2	83.3	23.5
9	3	-1	1	-1	-1	23.2	16.4	15.2	85.0	29.3
16	3	-1	-1	0	-1	9.6	6.6	6.3	90.9	31.3
17	3	1	0	0	-1	20.0	12.6	11.8	90.2	37.0
18	3	0	1	0	-1	26.4	16.4	14.2	82.0	37.9
25	3	0	-1	1	-1	10.4	4.7	4.4	95.0	54.8
26	3	-1	0	1	-1	15.4	11.6	11.2	90.5	24.7
27	3	1	1	1	-1	28.0	15.6	14.4	91.2	44.3
34	3	-1	-1	-1	0	9.6	7.4	6.6	73.3	22.9
35	3	1	0	-1	0	18.0	13.8	12.2	72.4	23.3
36	3	0	1	-1	0	25.8	17.8	16.0	81.6	31.0
43	3	0	-1	0	0	10.6	6.4	6.1	93.3	39.6
44	3	-1	0	0	0	15.4	11.8	10.0	66.7	23.4
45	3	1	1	0	0	27.2	19.2	15.7	69.6	29.4
52	3	1	-1	1	0	12.4	7.2	7.0	96.3	41.9
53	3	0	0	1	0	17.2	11.8	10.8	84.4	31.4
54	3	-1	1	1	0	23.6	14.6	12.4	80.4	38.1
61	3	0	-1	-1	1	10.8	8.6	7.2	61.1	20.4
62	3	-1	0	-1	1	14.8	12.2	11.4	76.5	17.6
63	3	1	1	-1	1	27.4	22.6	20.4	68.6	17.5
70	3	1	-1	0	1	12.4	9.8	8.8	72.2	21.0
71	3	0	0	0	1	17.0	13.4	12.0	72.0	21.2
72	3	-1	1	0	1	25.0	19.4	18.0	80.0	22.4
79	3	-1	-1	1	1	9.2	5.1	4.6	89.1	44.6
80	3	1	0	1	1	19.2	15.0	13.8	77.8	21.9
81	3	0	1	1	1	26.2	18.8	17.4	84.1	28.2

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