Michigan Machine Tool Conference
(1962 : University of Michigan)

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PROCEEDINGS OF THE MICHIGAN MACHINE TOOL CONFERENCE

March 28-29, 1962

Edited by
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Industrial Development Research Program
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THE UNIVERSITY OF MICHIGAN
Ann Arbor, Michigan

PREFACE

The Michigan Machine-Tool Conference was held at the University of Michigan on March 28-29 with top executives of the industry in order to acquaint them with the plans and objectives of a study of the industry in Michigan, to better acquaint them with the research activities and resources of the University and to enlist their cooperation in the survey to follow. The purpose of the study is to determine how science and technology may be more effectively utilized to promote the growth of the machine-tool industry in Michigan. Another study is to be made simultaneously of the electronics industry in Michigan.

Although essentially a report of talks given at the Michigan Machine-Tool Conference, the papers have been slightly rearranged; in a few cases, the contents have been amplified by the respective authors to give a somewhat fuller picture than was possible at the Conference. It is important to note that the Conference was not held so much to report the results of a completed study, as to discuss the initiation of a study.

The material therefore presented was chosen to describe the nature and scope of the proposed study of the machine-tool industry in Michigan and to indicate the information on hand at the point of departure for the study. Other presentations were selected to describe the diverse resources within the University available to assist both in the study and in the implementation of possible programs which may develop from findings.

The introduction which follows explains why the study is being made and describes the methodology to be employed. Parts of the next section summarize available information concerning the economic and technological trends in the industry, and include comments concerning the future of the industry in Michigan. This material is followed by a discussion of research experience in metal cutting at the University of Michigan, including important findings from recent research activities here.

The general availability of engineering and scientific resources at the University for assistance to industry is next discussed, followed by specific attention to the role of the Institute of Science and Technology. The report concludes with a summary of University resources in business and economics also available to assist industry.

CONTENTS

Mr. Bacon has assumed the major responsibility for formulating the Industrial Development Research Program and is its first Director. Mr. Bacon holds degrees in engineering (B.S.E.E., 1952) and in business (M.B.A., 1955) from The University of Michigan and has completed most of the requirements for the Ph.D. He has been associated with the University in various engineering and operations research capacities since 1953, with the exception of 1956-1957, when he was a Supervisor in Long-Range Product Planning with Remington Rand Univac. He recently served in a consulting capacity to IBM concerning the development of quantitative techniques for long-range product planning.

Section I

SOME ECONOMIC AND TECHNOLOGICAL ASPECTS
OF THE MACHINE-TOOL INDUSTRY

Dr. Chastain (Ph.D., University of Michigan, 1958) is a Research Associate in the Industrial Development Research Program and was formerly associated with Johns Hopkins University and the University of Arkansas. Dr. Chastain

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has also been a financial and research accountant with the U.S. Securities and Exchange Commission.

Mr. DeVries, Research Associate in the Industrial Development Research Program, holds both engineering (B.S.E., 1959) and business degrees (M.B.A., 1960) from the University of Michigan. Mr. DeVries is also a part-time instructor in the Industrial Engineering Department and a doctoral student.

Dr. Schmidt has had foreign experience (mechanical engineer with the Carl Zeiss Optical Works in Germany for 9 years prior to World War II), teaching experience (Colorado State University, University of Illinois, and Marquette University), and industrial experience in this country (Research Engineer in charge of Metal Cutting and Chief Research Engineer of Kearney and Trecker Corporation, Milwaukee, Wisconsin from 1943 to 1961). He is currently Professor of Mechanical Engineering at Marquette University.

Professor Emeritus Boston taught at The University of Michigan from 1914 until his retirement in 1956, with intervals for service in the Navy and in industry. He established the Production Engineering Department and was its chairman until 1956. Professor Boston is internationally known for his research, consultation with industry and the American Standards Association, and his publications relating to machine tools. At present, he is consultant for the Materials Advisory Board of the National Academy of Sciences.

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Section II

UNIVERSITY RESEARCH IN MACHINE TOOLS AND MACHINABILITY

Professor Colwell (B.S.E., 1935, M.S. 1938, University of Michigan), has been associated with the University faculty since 1937 and prior to that was an engineer with Tennessee Eastman Corporation (1935-1937). In addition to wide experience as a consultant to industry, he has authored numerous publications dealing with metalworking. Professor Colwell is currently an active member of University committees on research and education and is serving as a consultant to the Industrial Development Research Program.

Section III

GENERAL UNIVERSITY RESEARCH CAPABILITIES

Mr. Burroughs, Director of Research Administration at the University of Michigan, holds a B.Sc. from North Carolina State College (1925). Mr. Burroughs has extensive industrial experience, including work as a physicist with Kodak Research Laboratories from 1926 to 1942 (with a two-year period as Research Fellow at Purdue University) and as an engineer with the General Electric Company from 1945 to 1956. During the war he served as a Commander in the U.S.N.R. Since 1956 he has been associated with the University in directing research.

Dr. Evaldson (Ph.D., Stanford University, 1950), Associate Director of the Institute of Science and Technology, was Senior Analytical Engineer with the United Aircraft Corporation (1941-1947) and Engineering Consultant for Booz, Allen and Hamilton from 1950 until 1953, when he joined the University of Michigan faculty. Dr. Evaldson was granted an extended leave of absence from his teaching duties as Professor of Mechanical Engineering to serve as Associate Director first of Willow Run Laboratories, and then of the Institute of Science and Technology.

Dr. Swinyard, Director of the Bureau of Business Research, received his Ph.D. from Syracuse University and was Professor of Marketing at that school from 1946 to 1956. From 1956 until early this year, he was Director of Management Research for Booz, Allen and Hamilton, a management consultant firm with headquarters in Chicago.

INTRODUCTION

The Industrial Development Research Program and the Machine-Tool Industry

Frank R. Bacon, Jr.

The Institute of Science and Technology was established at the University in July, 1959, to serve as a center of science and technology for the state, and to promote the economic growth of the state by facilitating the use of science and technology by industry. In carrying out these functions, the Institute operates many of the University's research and development facilities, supervises many of its programs in the physical sciences, sponsors "seed" research projects of potential benefit to the state, and sponsors visiting professors, lecturers, and fellows in various fields of science and engineering.

About a year ago the Institute established a special research program, the Industrial Development Research Program, to study how science and technology might be better utilized to promote the growth of Michigan industry. The Industrial Development Research Program investigates the means by which this objective can be realized. The Program is guided by an advisory committee, of which Professor Paul W. McCracken of the University's School of Business Administration is Chairman. The Committee includes members from the Industrial Engineering Department of the College of Engineering and from the Economics Department of the College of Literature, Science, and the Arts. A liaison office has also been established in conjunction with the Research Program to provide more effective communication between the University and industry.

The basic reasons for the decline in the Michigan economic growth rate are generally well known. These are the decentralization of the automobile industry and establishment of plants in other states, development by the automobile industry of increased capability for in-house production of components and accessories, and the shifting of defense expenditures from the state to other centers producing missiles and space products.

Careful study during the past year has led us to the conclusion that the most effective way for the Institute of Science and Technology to help renew industrial growth in Michigan is by aiding business with the development of new products and processes. In order to learn specifically what the Institute might do toward this objective, two industries have been selected for detailed study on a pilot basis—the machine-tool builders and the electronics industry.

The Michigan machine-tool industry represents a basic segment of the machinery industry in the state and has maintained a constant and significant share of a declining national industry in terms of value added. This industry has a key role in both the Michigan and U.S. economy in that it produces the equipment which must be used either directly or indirectly for producing other manufactured products. In national importance, Michigan is the third leading state, producing 9.8% of the country's machine tools.

The electronics industry, on the other hand, represents a contrasting situation where Michigan has maintained over the last ten years a small percentage of a rapidly growing research-based industry.

In discussions with business and university leaders concerning what approach should be made in studying product development activities, it became apparent that the degree of understanding required in order to be truly helpful to firms would necessitate an analysis in depth of all significant functions related to product development. Throughout the past year an interdisciplinary research team representing a number of business, economics and engineering fields has developed such a method of analysis. Since decisions about product development and diversification must ultimately be made individually by firms, it was concluded that the basic unit of analysis must be the firm itself. However, decisions concerning product development must also be made within broader industry contexts which reflect growth trends in comparison with other industries, and location advantages and disadvantages with respect to markets, suppliers, and supporting scientific and technological capabilities.

The identification and consideration of technological factors are an important part of our study because these factors may have a decided influence on the location of economic activity. The ability of a firm to engage in the development of new products is directly dependent on the technological resources available to it both internally and externally. We are especially interested in any business need for additional external resources which might be made available through the supporting basic and developmental research conducted by universities, independent research laboratories, and industry within the same geographic area. We need to know how important to the growth of Michigan industry would be the availability of additional engineering development services and testing beyond the present activities of our major universities in conducting research and providing courses, seminars, and lectures.

It is particularly important to identify as soon as possible any gaps in fundamental research which should be filled to promote the growth of new industries in Michigan. For example, national leaders concerned with our country's security have expressed interest in the centralization of some research activities in machine tools, the accumulation of recent metalworking knowledge, and an inventory of research facilities available in individual firms. Such centers have already been established in some foreign countries, notably England. It is an open question at this time whether or not this would be the correct approach here. The present study is designed to throw light on this question. If such centers should seem desirable, they might well be located at some of the leading universities. These centers could provide national leaders, industry officials and other interested parties with information on the state of the art in a given area, could direct them to firms or other sources with capabilities for doing research on a given problem, and could render some direct aid and consultation services. For instance, the capabilities and accomplishments of this University in metalworking research, as well as in other areas, may not be known to many company executives nor to some national leaders interested in the progress of machine-tool production.

Allegations have been made that the American machine-tool industry does not devote enough resources to research and development and to seeking progress through better machines and reduced costs. As yet, not a great deal is known about the factors which are responsible for the degree of new developments within an industry. In our study, which is continuing, we will attempt to gain increased knowledge of some of these factors, such as the influence of company resources and financial ability, managerial attitudes and motivation regarding technological change, and the role of company goals concerning future progress. To provide the depth of analysis needed within individual firms, activities associated with six functional areas relating to product development will be examined. These include the following:

Functions	Activities
1. Idea Origination	Engineering & Scientific Research Marketing & Market Research Other
2. Engineering Development	Engineering Breadboard Design & Test Engineering Prototype Design & Test Engineering Production Model Design & Test
3. Production	Development of New Production Machinery Design & Construction of Tools, Dies, & Fixtures Process Engineering, Routing, etc. Pilot Production Operations Full Production Operations
4. Marketing	Market Research--Market Testing Distribution, Selecting of Channels Advertising and Promotion Packaging Sales Force

Functions	Activities
5. Finance	Capitalization Structure Source of Funds for Research and Product Development Ease or Difficulty of Obtaining Funds
6. Management	Organization for Product Development Planning, Controls Growth Objectives

This study places particular emphasis on the research projects now under way, the volume of present sales from products introduced or modified within recent years, the steps and costs involved in developing these products, the relationship of product development capabilities to competitive situations, and the relationship between product development and firm growth or success.

To obtain this information, a special prestructured questionnaire has been designed which makes it possible to obtain the necessary information with a minimum of effort on the part of company personnel. Two-man interview teams are scheduled to interview a 50% sample of machine-tool and electronics firms in Michigan during the summer 1962.

In addition, for the machine-tool industry some comparative data will be obtained concerning the product development activities of European machine-tool builders, and the amount of supporting research conducted in technical universities and institutes in Europe.

For the pilot study of these two industries there will be no charge to the firms involved, and cooperating firms will receive a copy of the completed questionnaire form on their firm which they may compare with published industry totals at the conclusion of the study. A preliminary report containing the significant findings will be presented to industry representatives at a conference some time during the fall of 1962.

In summary, this investigation is designed to enable our staff (1) to better understand the product development process, (2) to learn to what extent there is a gap, if any, in product development capabilities of Michigan firms in these industries, and (3) to render immediate assistance, if it is desired, to firms with product development problems, and (4) to determine what additional steps, if any, should be recommended to the University or industry to enhance the growth of these industries, especially within Michigan.

This study, if it is to be successful, will require the fullest support and cooperation from the firms in these two industries in Michigan. We are very pleased with the extremely favorable reaction the study has already received from a number of firms which cooperated during the pretest phase. We are confident that the benefits to each firm individually and to the industry as a whole will furnish a generous return on the effort expended. We in the Institute of Science and Technology are dedicated to this purpose.

Section I

SOME ECONOMIC AND TECHNOLOGICAL ASPECTS OF THE MACHINE-TOOL INDUSTRY

1

THE MACHINE-TOOL INDUSTRY: SOME IMPORTANT ECONOMIC TRENDS

Clark E. Chastain and Marvin G. DeVries

The machine-tool industry, often described as one of feast or famine, is the foundation of our modern machinery industry. As we know, machine tools are indispensable in manufacturing and in product development; every manufactured product is made directly or indirectly by one kind of machine tool. Consequently, the progress and the state of the art of the machine-tool industry, and the technology it employs, are critical factors in broadening the industrial base and increasing the industrial output of the United States and of Michigan.

The machine tool industry tends to locate near the industrial complex for which it supplies equipment. Hence we find that the leading U.S. machine-tool producers are located in the Eastern and North Central states, notably in Michigan, Ohio, Illinois, the Philadelphia district, and southern New England. Although Ohio leads all states in value of output of metalworking machinery, Michigan is noted for its specialization in cutting tools, jigs, and fixtures.[1]

I. Industry Description

The study currently under way by the Industrial Development Research Program of The University of Michigan's Institute of Science and Technology is concentrated on the metal-cutting and metal-forming firms as outlined by the Department of Commerce. The Department has divided the manufacturing sector of our economy into 21 separate industries, numbering them, for purposes of its own classification, 19 through 39. The machinery industry (excluding the electrical industry) is number 35, and is subdivided into nine 3-digit industries:

351	Engines and Turbines
352	Form Machinery and Equipment
353	Construction, Mining, and Materials-Handling Machinery and Equipment
354	Metalworking Machinery and Equipment
355	Special Industry Machinery, Except Metalworking
356	General Industrial Machinery and Equipment
357	Office, Computing, and Accounting Machines
358	Service Industry Machines
359	Miscellaneous Machinery, Except Electrical

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[1] W. S. Woytinsky and E. S. Woytinsky, World Population and Production: Trends and Outlook, New York; The Twentieth Century Fund, 1953, p. 1149.

The metalworking machinery and equipment industry is in turn subdivided into five 4-digit industries:

3541	Machine-Tools, Metal Cutting Types
3542	Machine-Tools, Metal Forming Types
3544	Special Dies and Tools, Die Sets, Jigs and Fixtures
3545	Machine Tool Accessories and Measuring Devices
3548	Metalworking Machinery, Except Machine Tools

As mentioned above, the analysis being performed by the Industrial Development Research Program deals with the metalworking machinery industry in general and with the metal-cutting and metal-forming industries in particular. (See Exhibit 1 for the relationship of the machine-tool industry to the metalworking and machinery industries.)

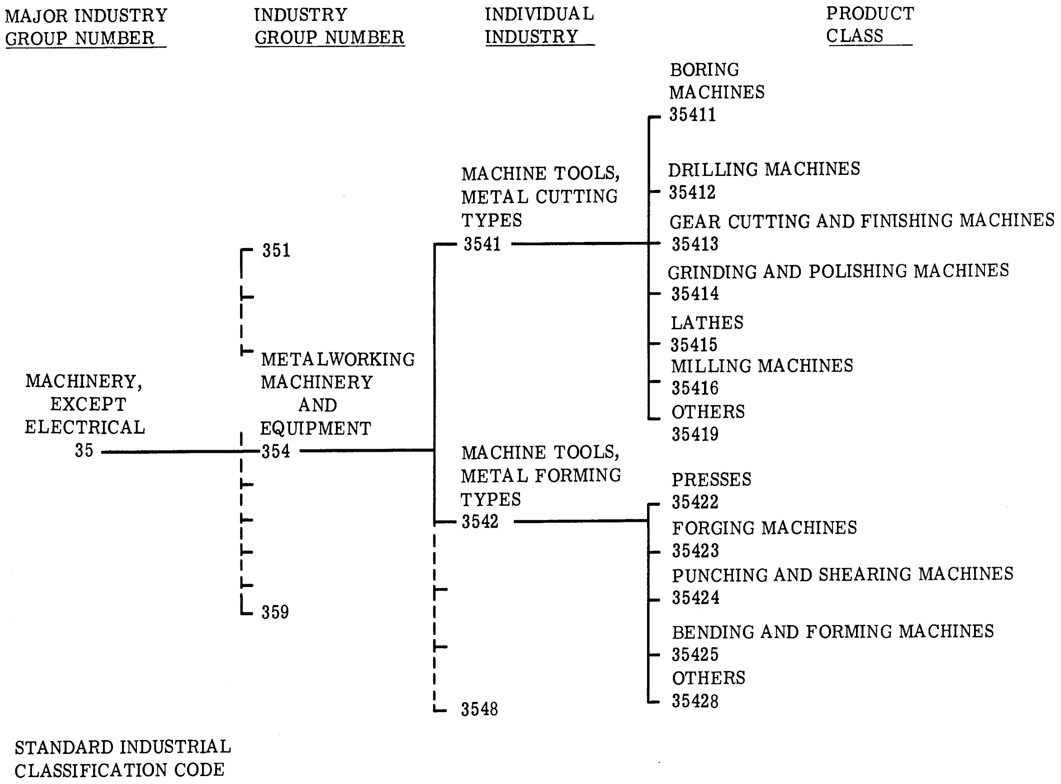

EXHIBIT 1

In 1959 the whole machinery industry (35) had 1,400,000 employees; the metalworking machinery industry (354) had 244,000 employees; and the machine tools industries (3541 and 3542) had 75,000 employees.[2] Value added or sales less materials and supplies purchased was $14,545 million for the machinery industry; $2,490 million for the metalworking machinery industry; and $747 million for the machine tools industries. The trends in value added by each of these three industries is presented in Exhibit 2.

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[2] Bureau of the Census, Annual Survey of Manufactures, "General Statistics for Industry Groups and Selected Industries, 1959 and 1958," M59 (AS)-1, pp. 14-15.

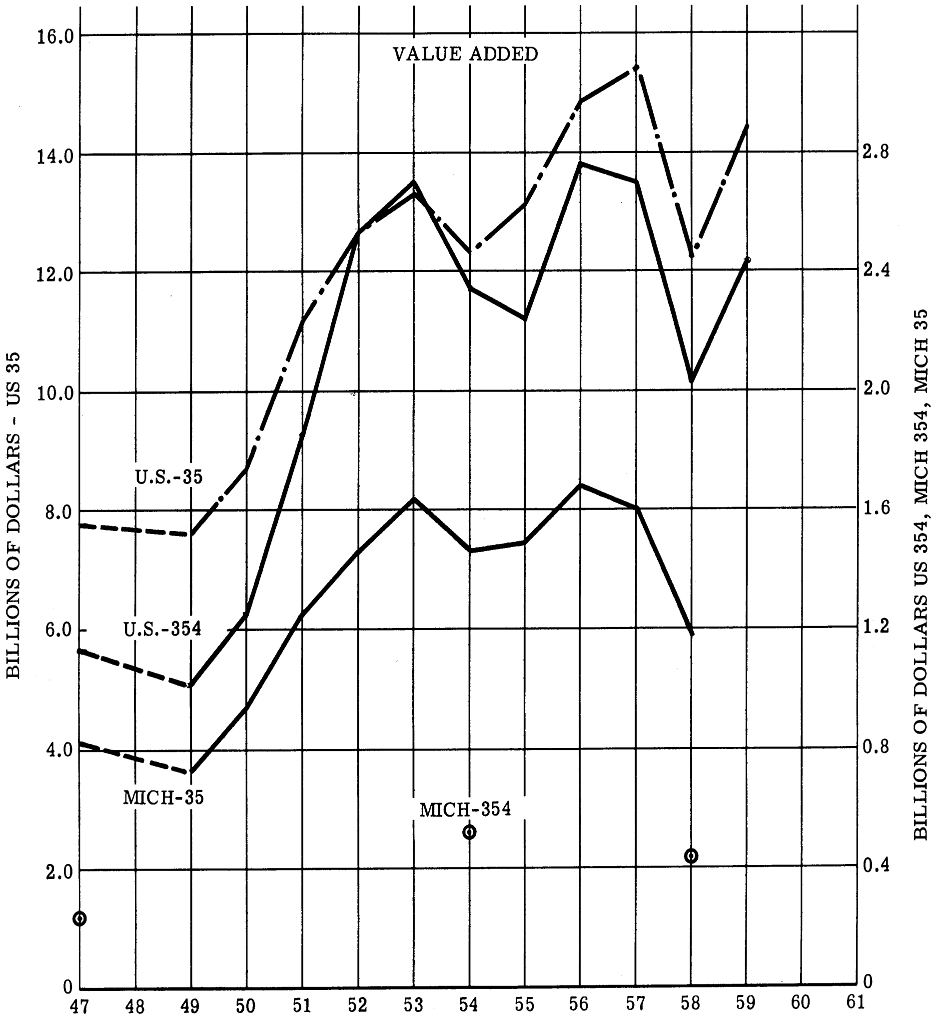

EXHIBIT 2

In 1959 the machine tool industry employed 30.7 percent of all metalworking employees and 5.4 percent of all machinery employees; these percentages may be compared with value added percentages of 30.4 and 5.2 for the metalworking and machinery industries, respectively. Value added per employee was $10,087 for the machine tool, $10,185 for the metalworking, and $10,308 for the machinery industry; trends for each industry for the period 1947-1959 are given in Exhibit 3. In 1959, employees, sales and value added within the machine tool industry were distributed as follows:[3]

	Total	Metal Cutting	Metal Forming	Percent Metal Cutting	Percent Metal Forming
Employees	75,091	52,797	22,294	70.3	29.7
Sales (000)	$1,111,496	$753,784	$357,712	67.8	32.2
Value Added (000)	$ 737,451	$505,433	$232,018	68.5	31.5

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[3] Bureau of the Census, op. cit., pp. 14-15.

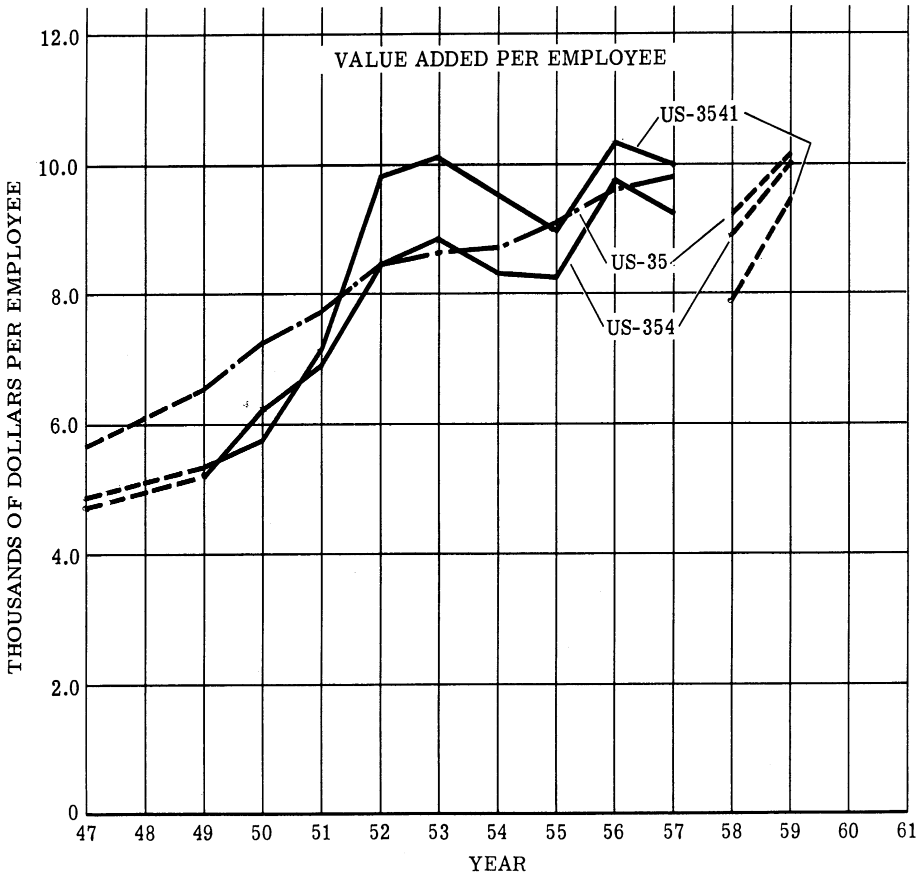


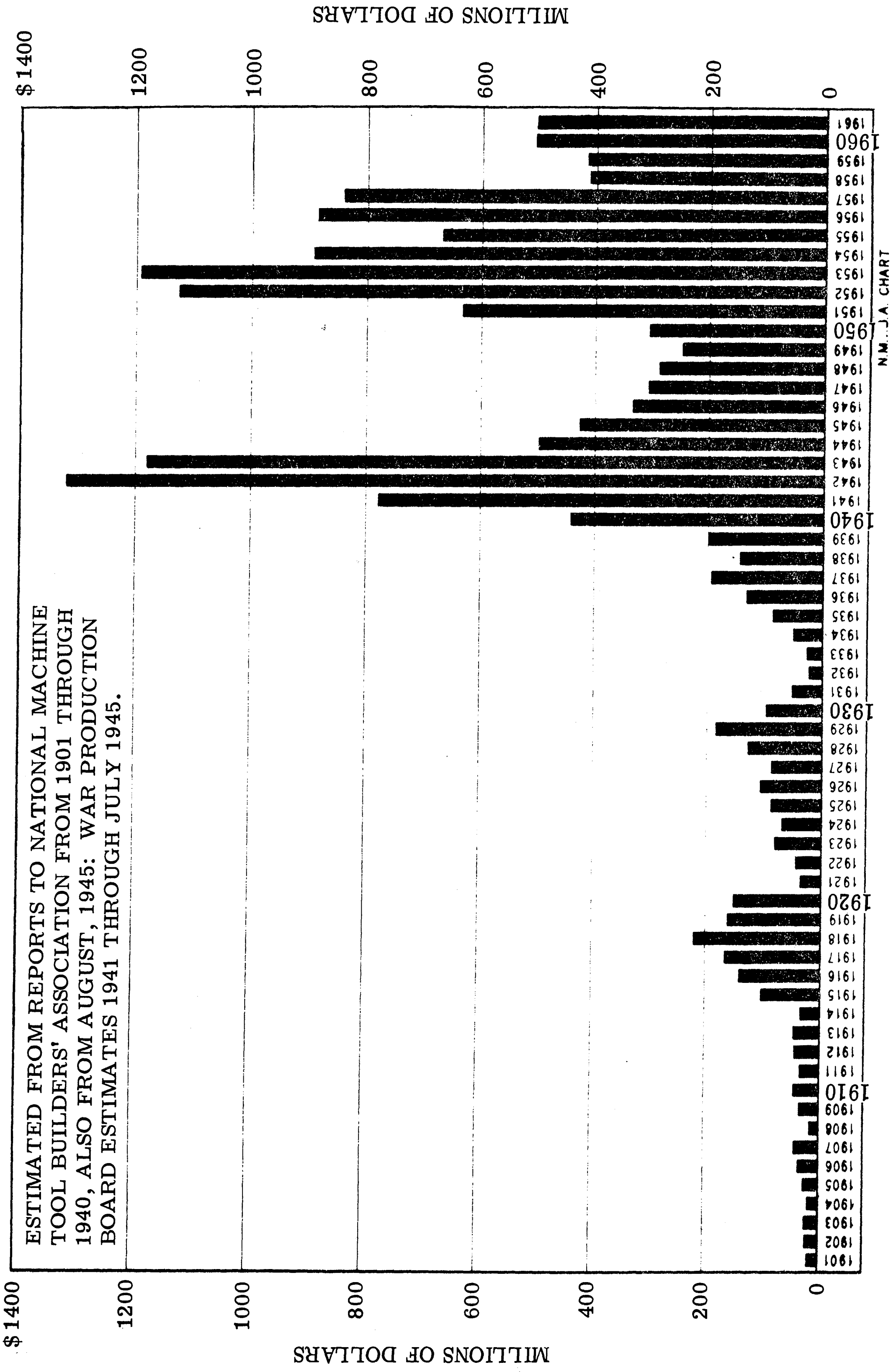
EXHIBIT 3

II. Trend of Sales, Employees and Value Added

Machine tool sales have been rising fairly steady since 1900, and three of the four sales peaks have coincided with three wars: World War I, 1915-1920; World War II, 1940-1946; and the Korean War and continuing cold war build-up, 1951-1957. One other peak period in machine tool production and sales occurred from 1926-1930, a period during which this country's peace-time industrial base was rapidly being increased. This trend as reflected in shipments of metal-cutting tools is shown in Exhibit 4, and recent data for both the metal-forming industries are given in Table 1. The value of shipments for products classified in 5-digits under the metal-cutting industry are given for the years 1947-1960 in Exhibit 5.

One significant fact revealed by Table 1 is that during the 1950's metal-forming tools retained a fairly constant share of the machine tool market. Metal-forming tools constituted 32 percent of the market in 1950, fell to 19 percent in 1952, rose to 39.7 percent in 1957, and by 1959 had reverted to 32 percent. During the decade, metal-cutting tools constituted from two-thirds to three-fourths of the market; the number sold fell

MACHINE TOOL SHIPMENTS
Metal Cutting Type (3541)



ESTIMATED FROM REPORTS TO NATIONAL MACHINE TOOL BUILDERS' ASSOCIATION FROM 1901 THROUGH 1940, ALSO FROM AUGUST, 1945: WAR PRODUCTION BOARD ESTIMATES 1941 THROUGH JULY 1945.

EXHIBIT 4

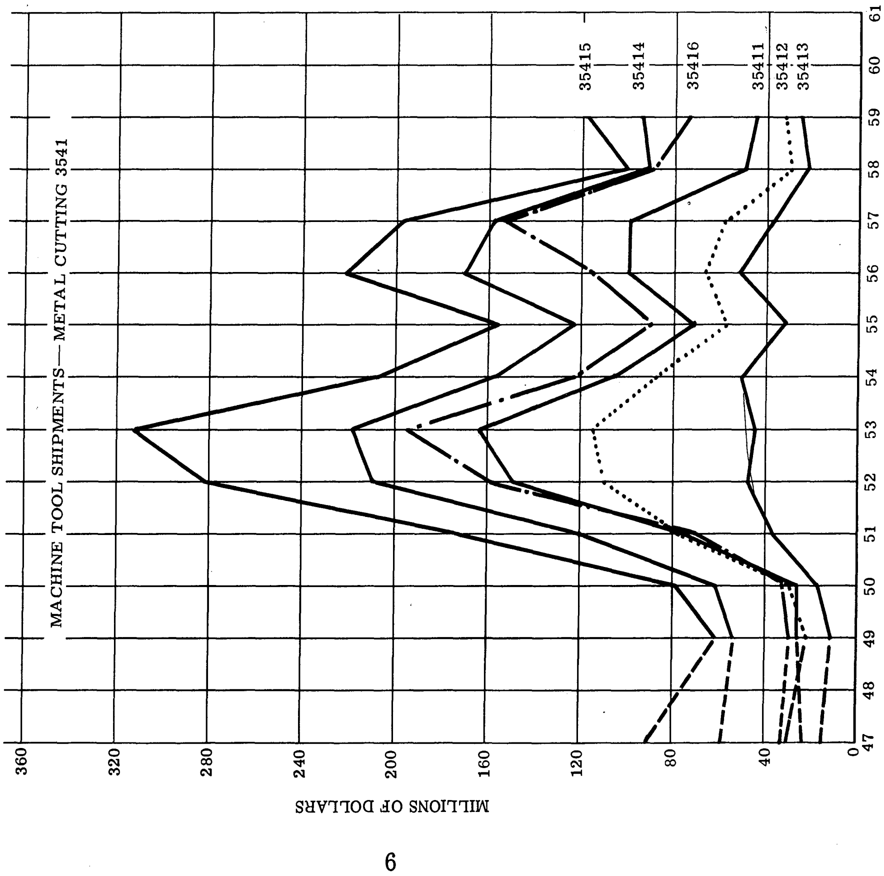


EXHIBIT 5

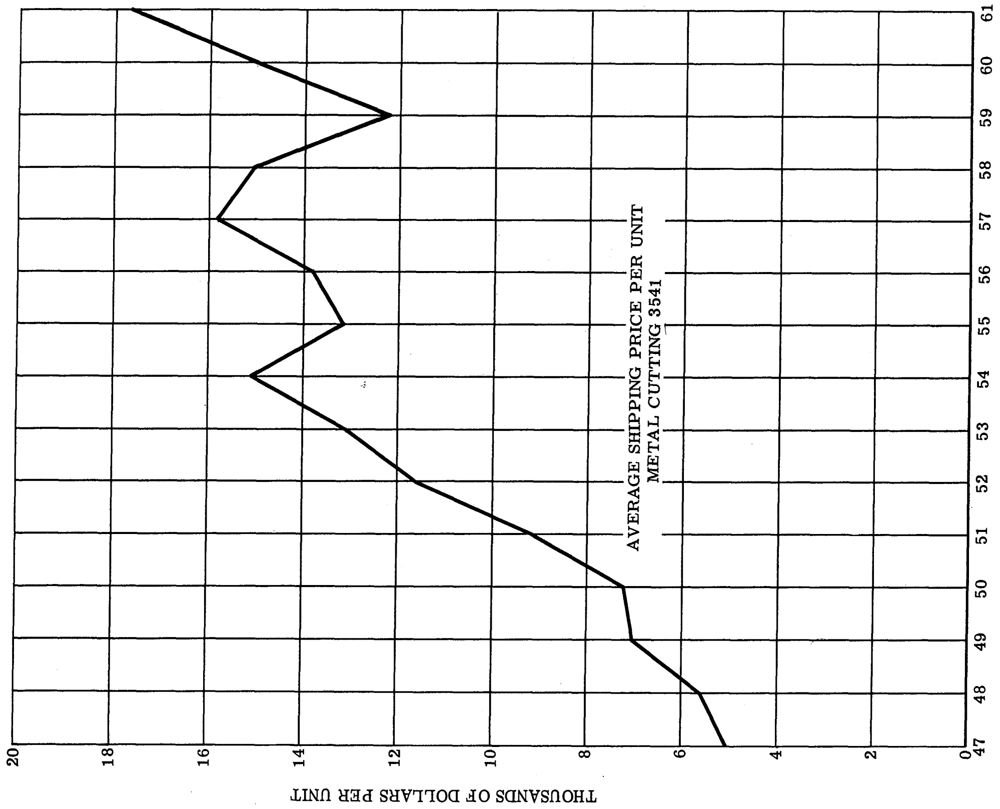


EXHIBIT 6

DATA: NATIONAL MACHINE TOOL BUILDERS ASSOCIATION, "UNITS AND VALUE OF MACHINE TOOL SHIPMENTS: METAL CUTTING TYPES ONLY" FEB 26, 1962.

Table I

SHIPMENTS OF MACHINE TOOLS[4]

Year	Metal Cutting	Metal Forming	Total	Metal Cutting[1]
	(thousands of dollars)			(Units)
1950[2]	486,662	229,336	715,998	41,500
1951[2]	953,124	319,109	1,272,233	70,800
1952[3]	1,114,608	240,774	1,355,382	96,800
1953	1,138,141	248,057	1,386,198	91,500
1954	821,450	251,349	1,072,799	58,500
1955	633,794	207,034	840,828	50,500
1956	833,665	304,482	1,138,147	63,900
1957	793,353	257,962	1,051,315	53,700
1958	422,496	148,654	571,150	27,400
1959	447,009	177,192	624,201	33,900
1960	520,294	206,864	727,158	34,000
1961	501,171	219,940	721,111	28,600

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[1] National Machine Tool Builders Association, "Units and Value of Machine Tool Shipments: Metal Cutting Types Only," February 26, 1962.

[2] Bureau of the Census, Annual Survey of Manufactures for 1950 and 1951.

[3] Data for the year 1952-61 were taken from U.S. Department of Commerce, Business and Defense Services Administration, Metalworking Equipment Divisions, "Machine Tool Industry: Outlook for 1962 and Review of 1961," January 22, 1962.

[4] The value of shipments reported by different sources varies considerably. The highest figures are those reported by the Survey of Manufactures.

(thousands of dollars)

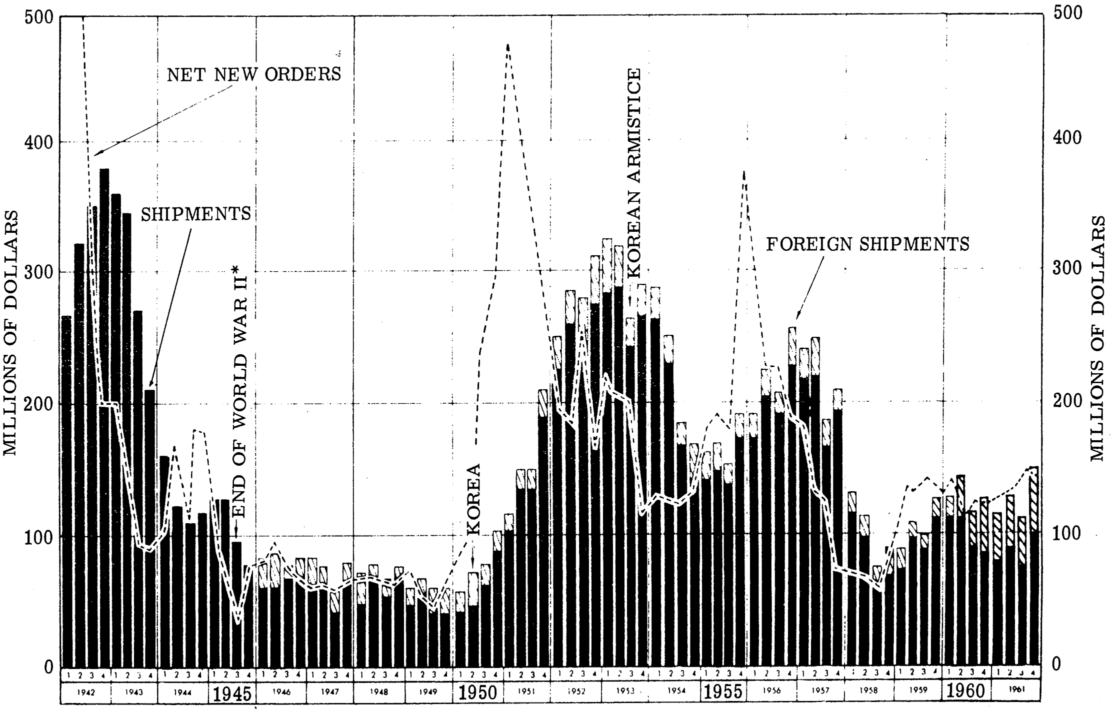
1950	715,998	1955	1,385,157
1951	1,272,233	1956	1,727,457
1952	1,927,953	1957	1,719,385
1953	1,970,873	1958	983,681
1954	1,583,704	1959	1,111,496

The data from the Business and Defense Services Administration, quoted above, constitute median values; as noted in Exhibits, still lower figures have been published by the National Machine Tool Builders Association. It is assumed that the over-all variation can be attributed to such factors as variation in firms covered, variation in the kinds of product included, and variations in the reporting unit (i.e., establishments versus firms).

from 41,500 units in 1950 to 33,900 in 1959, meanwhile rising to a peak of 96,800 in 1952. On the basis of figures supplied by the National Machine Tool Builders Association, the average cost of each cutting tool sold rose from $7,363 in 1950 to $12,175 in 1959, and $17,726 in 1961 (see Exhibit 6). Fewer units were sold per year because the individual units are generally performing a greater number of functions, and because there has been a decline in government purchases as well as a general decline in industrial demand due to the accumulation of large stocks and the availability of second-hand machines from wartime surpluses. The higher cost per machine is a result of higher production costs, the addition of technological improvements, and general inflationary trends.

The delay between order dates and time of shipment has been significantly lowered from the 2-year peak during the Korean Conflict. As shown in Exhibit 7, the delay currently averages 2 to 6 months. Exhibit 7 divides total shipments into domestic and foreign, and shows that foreign shipments have increased in absolute amount as well as in percentage of the total. Exports currently amount to about 30 percent of domestic sales. The importance of this enlargement of the foreign market is discussed in Section IV.

QUARTERLY SHIPMENTS AND NET NEW ORDERS OF MACHINE TOOLS
(METAL CUTTING TYPES ONLY - 3541)



*BREAKDOWN OF SHIPMENTS TO SHOW DOMESTIC AND FOREIGN DESTINATIONS NOT AVAILABLE FROM 1942 TO THIRD QUARTER 1945

▨ SHIPMENTS FOREIGN DESTINATIONS
■ SHIPMENTS DOMESTIC DESTINATIONS
------ NET NEW ORDERS

EXHIBIT 7

The number of employees in the industry has also fluctuated substantially. Table II shows the number of employees working in metal cutting since 1947; only 1958 and 1959 data are available for metal forming. Sales have, as would be expected, fluctuated more than the number of employees. For example, sales per employee in 1950 were approximately $8,800; in the peak year of 1952 they were $15,300, and in 1959 they were $14,200.

Value added by manufacture, usually considered the best measure for estimating an industry's relative importance, is shown in Table III. Value added is essentially sales minus the cost of materials, supplies, and utilities purchased.

In 1959, value added to the product as a percent of the sales price was about the same for metal cutting (67.1 percent) and metal forming (65.0 percent); this percentage

Table II

EMPLOYEES IN MACHINE TOOL INDUSTRY

Year	Metal Cutting	Metal Forming	Total
1959	52,797	22,294	75,091
1958	52,864	22,502	75,366
1957	79,895		
1956	85,469		
1955	77,063		
1954	80,959		
1953	99,494		
1952	102,735		
1951	83,855		
1950	54,747		
1949	52,384		
1948	NA		
1947	70,001		

Source: Bureau of Census, Annual Survey of Manufactures, for appropriate years.

Table III

MACHINE TOOL INDUSTRY
VALUE ADDED BY MANUFACTURE
(thousands of dollars)

Year	Metal Cutting	Metal Forming	Total
1959	505,433	232,018	737,451
1958	420,961	176,021	596,982
1957	797,541		
1956	882,188		
1955	690,980		
1954	743,569		
1953	1,000,000		
1952	1,003,344		
1951	588,863		
1950	316,740		
1949	272,732		
1947	343,198		

Source: Bureau of Census, Annual Survey of Manufactures for appropriate years.

has remained nearly constant for metal cutting since 1950. In other words, operating costs (excluding materials purchased) are constituting about two-thirds of the sales price of these products. Insofar as the amount of value added by a company increases, more functions are generally being performed by it; and assuming an equal or greater sales volume, higher profits may be expected. This is not always true, however. If a company is paying higher factor costs or is experiencing a decline in production or marketing efficiency—or if the selling price has declined--value added will increase as a percentage of selling price, even though profits may decrease.

III. Location of Machine Tool and Metalworking Industries

As stated in the introduction, the machine tool industry is concentrated in areas of high industrial activity. Employment in the major producing states is shown in Table IV as a percent of total employment for the industry. (See Exhibits 8 and 9 for geographical presentations of the locations of metal-cutting, metal-forming, and metalworking activities.)

Table IV

GEOGRAPHICAL DISTRIBUTION OF WORKERS IN THE METAL-CUTTING, METAL-FORMING, MACHINE-TOOL, AND METALWORKING INDUSTRIES[1]

State	Percent in Metal-Cutting Industry	Percent in Metal-Forming Industry	Percent in Machine-Tool Industry	Percent in Metalworking Industry
California	1.024	6.274	2.496	3.415
Connecticut	10.941	4.325	9.086	6.450
Illinois	7.784	23.382	12.158	10.237
Indiana	1.425	1.854	1.546	2.795
Massachusetts	7.311	2.371	5.926	8.022
Michigan	11.758	4.719	9.784	20.442
New Jersey	1.072	2.295	1.415	2.333
New York	4.856	9.049	6.032	4.737
Ohio	28.787	28.874	28.811	21.172
Pennsylvania	3.235	3.543	3.321	7.101
Vermont	5.749	.436	4.259	2.137
Wisconsin	7.165	1.280	5.514	3.314
All Other States	8.889	11.596	9.648	7.841
Total	100.0	100.0	100.0	100.0

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[1] Data are for the year 1960, and are restricted to firms employing 20 or more workers. Source: Iron Age, Basic Metalworking Data, Philadelphia, 1961.

The concentration of metal-cutting and metal-forming industries in the states of Michigan and Ohio are given in Exhibits 10 and 11 respectively. In Michigan the metal-cutting industry is centered around Detroit, where 75.3 percent of the work is performed, whereas the Lansing area is responsible for 53.7 percent of metal forming. As would be expected, the major centers of concentration in Ohio are the Cleveland and Cincinnati areas; between them they account for 81.0 percent and 53.6 percent of the state's important metal-cutting and metal-forming industries.

U. S. PLANT WORKERS IN PLANTS EMPLOYING 20 OR MORE
PER CENT OF MACHINE TOOL (3541 + 3542)
PER CENT OF METAL WORKING (354)

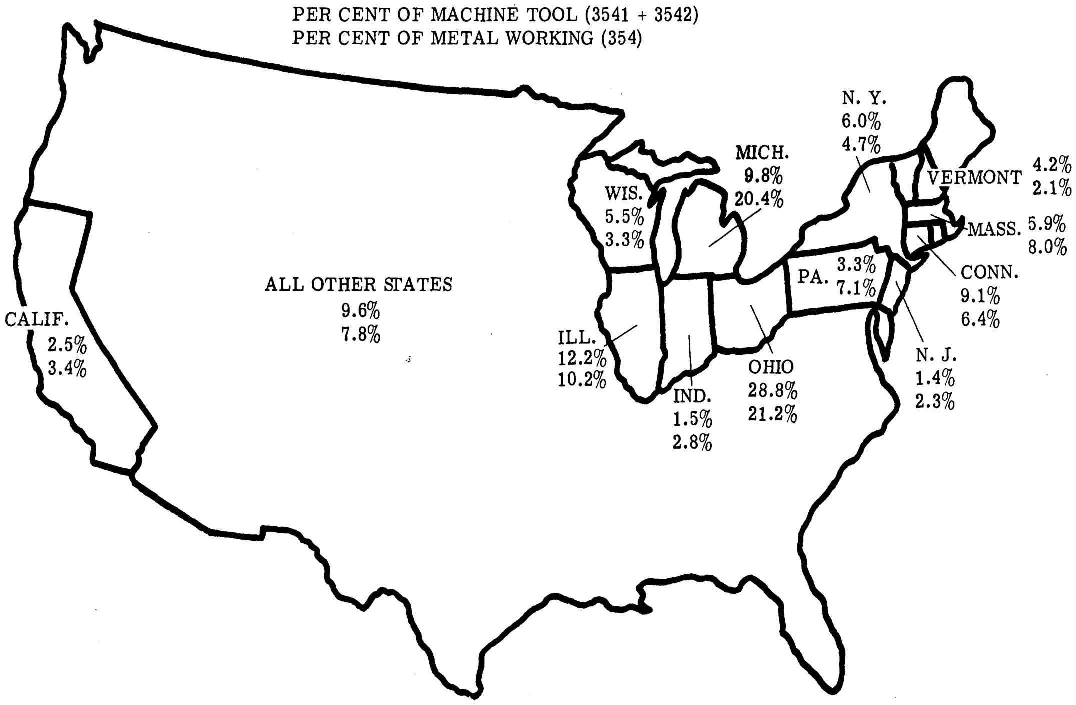


EXHIBIT 8

PLANT WORKERS IN PLANTS EMPLOYING 20 OR MORE

PER CENT OF METAL CUTTING (3541)
PER CENT OF METAL-FORMING (3542)

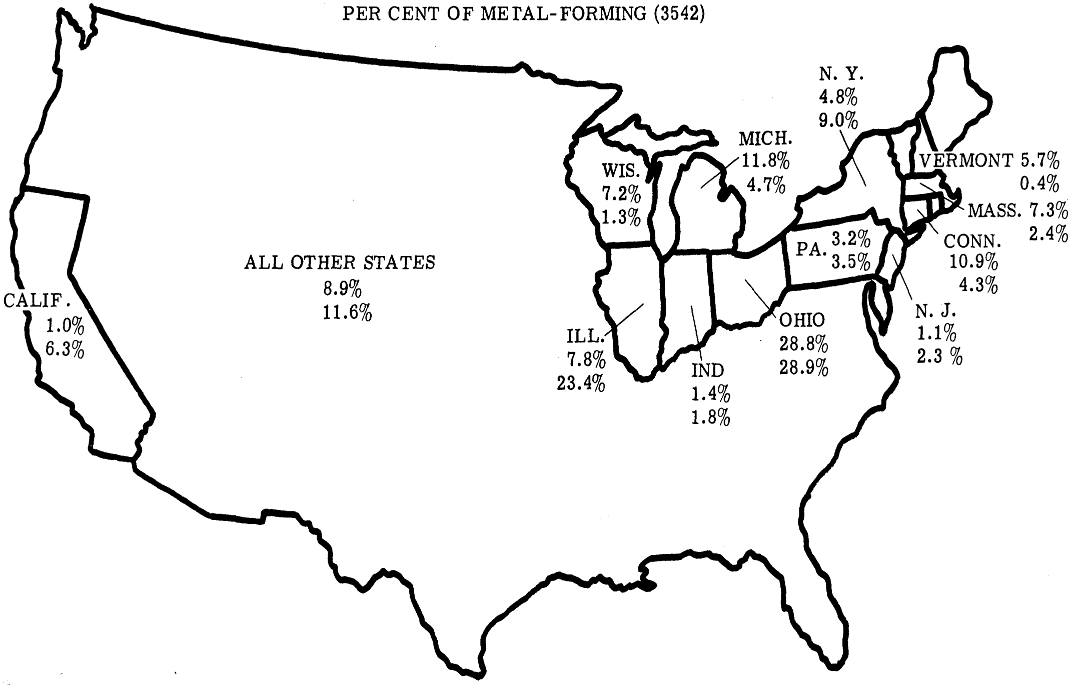
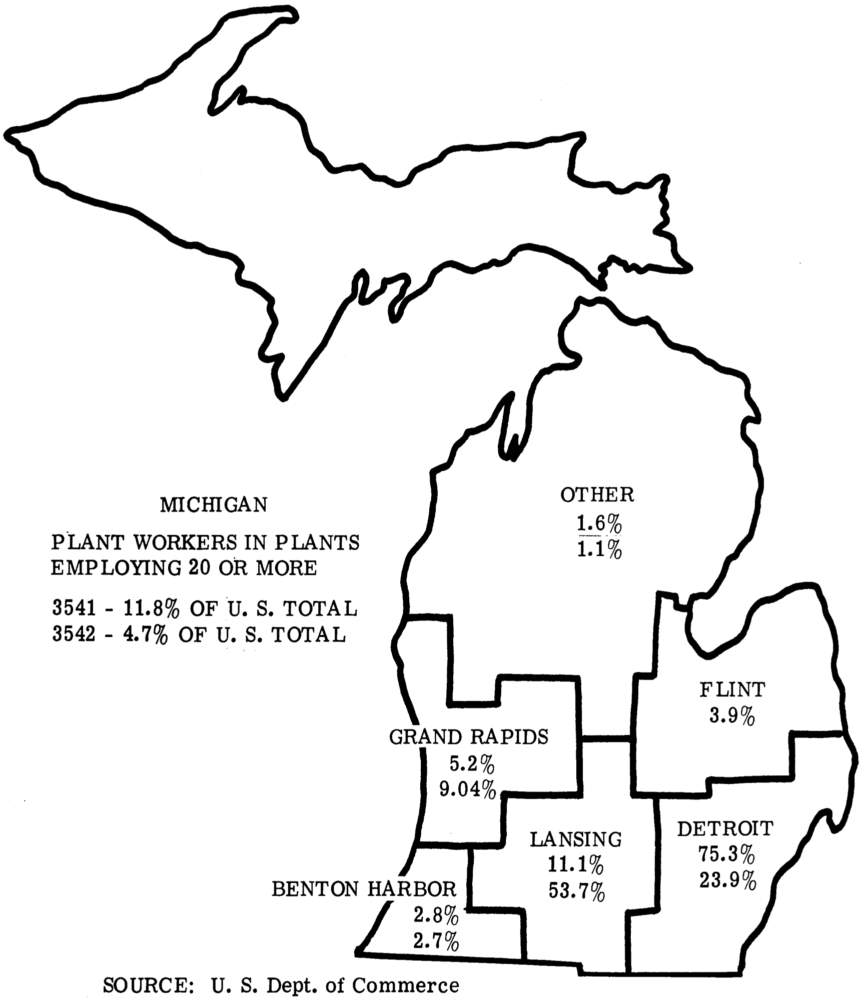


EXHIBIT 9



SOURCE: U. S. Dept. of Commerce

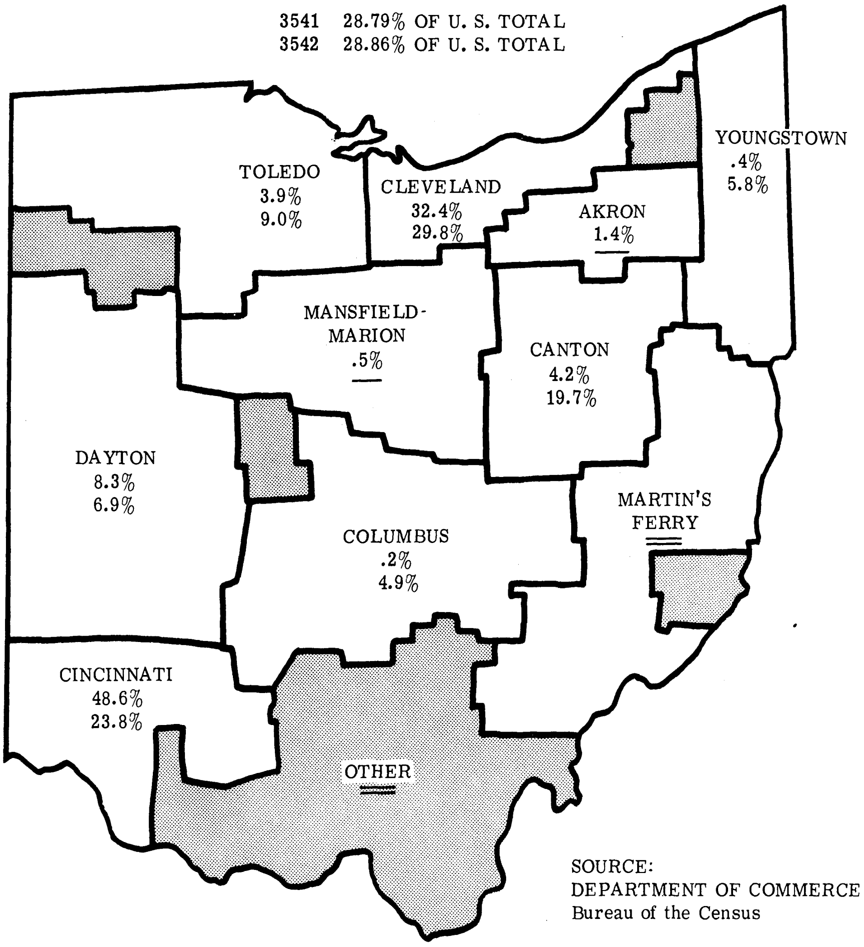
EXHIBIT 10

The importance of Ohio as the major producer of machine tools is indicated by its large proportion of total national employment, 28.8 percent. Illinois is the second largest producer (12.2 percent) followed by Michigan (9.8 percent) and Connecticut (9.1 percent). In over-all metalworking, however, Michigan's importance increases with 37,558 employees (20.4 percent) as compared with Ohio's 38,900 (21.2 percent). Table V shows the number of metalworking employees in each state, as well as the percent of the industry total for metal-cutting tools; for metal-forming tools; for special dies and tools, die sets, jigs, and fixtures; for machine tool accessories and measuring devices; and for other metalworking machinery. The number of establishments (by industry) is also shown for each state. Of particular interest is the fact that Michigan has more metal-cutting tool establishments than Ohio does (121 compared with 81), yet Ohio has 15,573 employees in comparison with Michigan's 6,361. The average of 53 employees in a Michigan metal-cutting plant and of

192 in a Ohio plant is strongly affected by the location of some of the country's largest metal-cutting plants in the Cincinnati and Cleveland areas. Further, metal-forming establishments are much smaller in Michigan than in Ohio, with an average of 26 versus 124 employees per plant.

OHIO

PLANT WORKERS IN PLANTS EMPLOYING 20 OR MORE



SOURCE:
DEPARTMENT OF COMMERCE
Bureau of the Census

EXHIBIT 11

IV. Foreign Developments

Exports and imports are important indicators of the extent to which the foreign and domestic markets of an industry are affected by foreign competition. In 1960 the foreign shipments of the U.S. machine tool industry constituted 23 percent of the industry's total shipments, compared with 32 percent in 1961. This trend, and particularly the level, is significant, since imports for both these years constituted approximately 8.3 percent of the domestic consumption of machine tools.

Table V

NUMBER OF EMPLOYEES AND ESTABLISHMENTS IN THE METALWORKING INDUSTRIES IN MICHIGAN AND OHIO

	Metal Cutting Tools	Metal Forming Tools	Special Dies, and Tools, Jigs, and Fixtures	Machine Tool Accessories	Other Metalworking Machinery	Total
Number of Employees						
United States	54,096	21,085	50,132	39,899	18,515	183,727
Michigan	6,361	995	19,008	10,834	360	37,558
Ohio	15,573	6,088	7,997	5,093	4,149	38,900
Number of Employees as a Percentage of National Totals for the Industries						
Michigan	11.8	4.7	37.9	27.2	1.9	20.4
Ohio	28.8	28.9	16.0	12.8	22.4	21.2
Number of Employees as a Percentage of Total State Employment in the Metal-working Industry						
Michigan	16.9	2.6	50.6	28.9	1.0	100.0
Ohio	40.0	15.6	20.6	13.1	10.7	100.0
Number of Establishments						
United States	627	291	5745	905	362	7930
Michigan	121	38	1097	265	32	1553
Ohio	81	49	662	83	53	928
Average Number of Employees per Establishment						
United States	86	72	87	44	51	-
Michigan	53	26	173	41	11	-
Ohio	192	124	121	61	78	-

Sources: The data on employees are from Iron Age, *Basic Metalworking Data*, 1961; they cover the year 1960 and include only the employees in plants which employ 20 or more. The data on the number of establishments are from the Bureau of Census, *Survey of Manufactures*, 1958.

However, other factors make it imperative that the United States carefully analyze its foreign competitive situation. Technological inroads are being made by foreign competitors (West Germany, Switzerland, Italy, and others): For example, observers have reported that West Germany is spending approximately $50 million annually in research and development on the mechanics of metal removal and metal forming. New technologies for the process of metal removal or at least improved means of exploiting the existing technology are almost certain to result. Another important factor is the temporary inability of many foreign producers to manufacture more machine tools because they lack facilities or skilled workers. Extensive training programs to increase the stock of skilled workers have been instituted in some countries. Moreover, since capital investment as a percent of the gross national product—the sum of the value of goods and services in the nation—is significantly higher for many foreign producers than it is for the U.S., it can be expected that their production capacities will rapidly be increased. A third factor is the price advantage enjoyed by foreign competitors, which reflects their lower manufacturing costs.

Exhibits 12 and 13 show the trend of exports and imports over the years 1947-1961 for the metal-cutting and metal-forming industries. The decline in exports from 1958 to 1959 was due primarily to a decline in milling machine and grinding machine shipments. The significant increase in 1960 was due primarily to increased shipments of automatic screw machines, gear-cutting machines, grinding machines, and multi-station machine tools. Most of the fluctuation over this period has been limited to metal-cutting tools; imports have remained relatively stable.

The trend of exports and imports as a percentage of total U.S. shipments is shown in Exhibit 14. The percentage of metal-cutting exports has been rising since 1951. Metal-forming exports declined until 1956, and since then have increased slowly. Although exports in dollar shipments have tended for some time to increase slightly, due primarily to a declining domestic market they have increased even more as a percentage of total shipments. Imports as a percent of U.S. total shipments have slowly increased since 1955.

Exhibits 15 and 16 show a 7-year trend of exports by area of destination for metal-cutting tools and metal-forming tools. The major purchasers of metal-cutting exports to Europe are the United Kingdom, Germany, and Italy. Over the 7-year period 1954-1960, the exports to the United Kingdom have fluctuated widely between $7 million and 18 million, the exports to Germany have increased from $4.5 million to 16.9 million, and the exports to France have constantly declined, from $11.4 million to 6.7 million. The decrease in the export of metal-cutting tools to North and Central America is due entirely to a decline in exports to Canada—from $19.8 million to 8.9 million. The major Asian

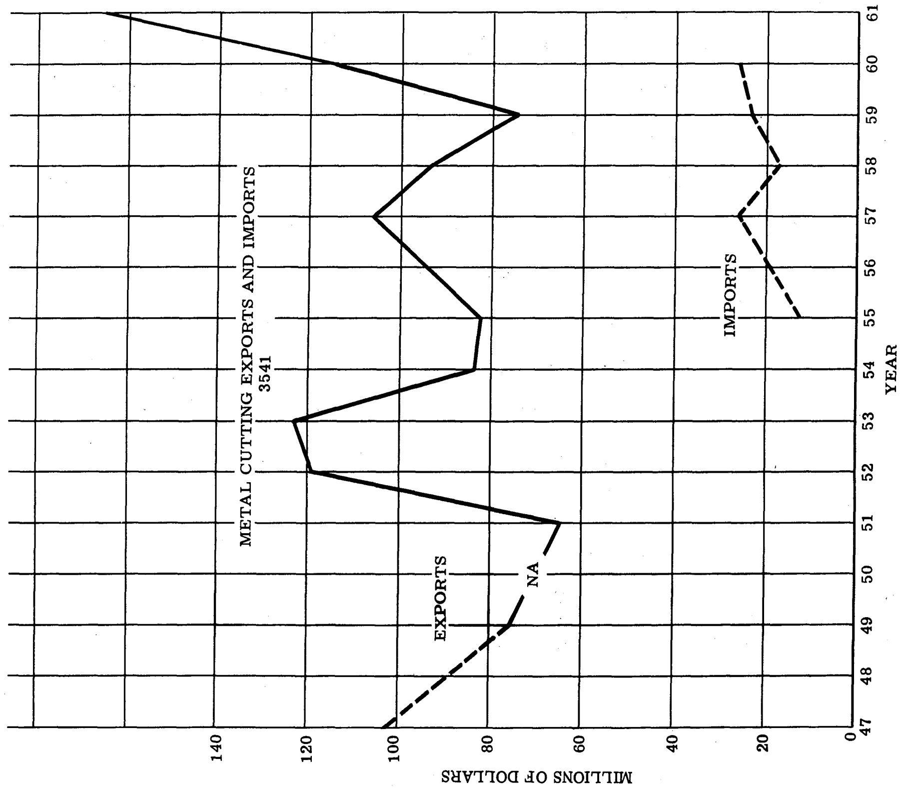


EXHIBIT 12

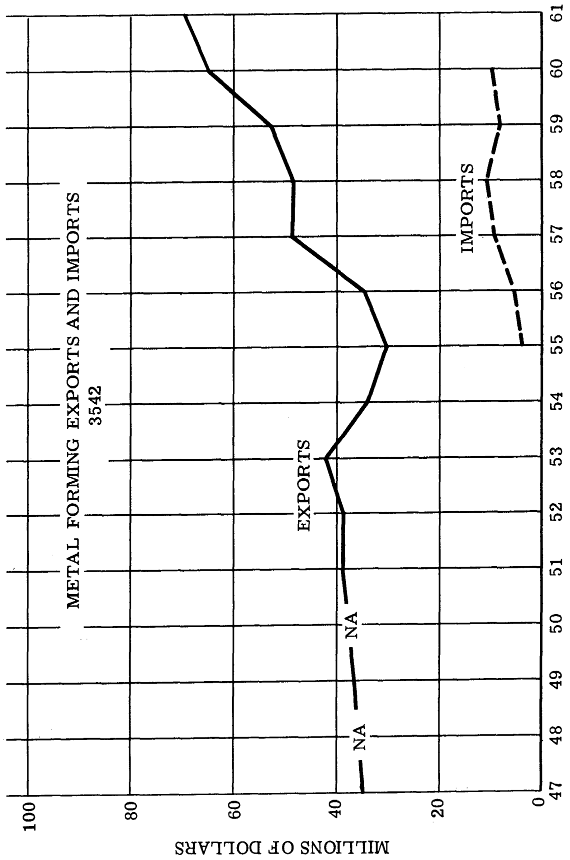


EXHIBIT 13

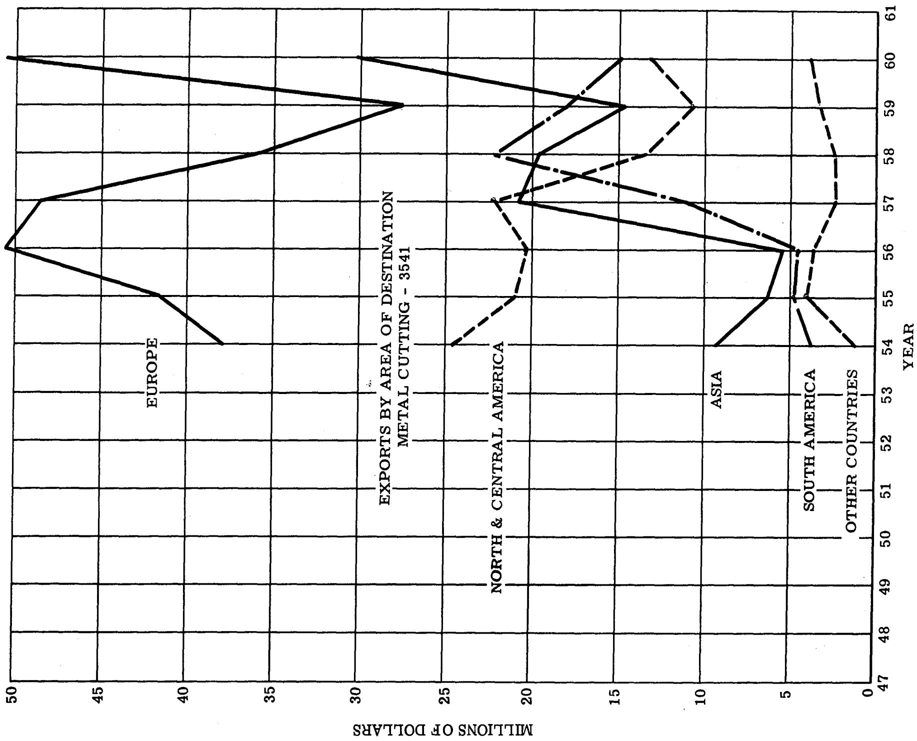


EXHIBIT 15

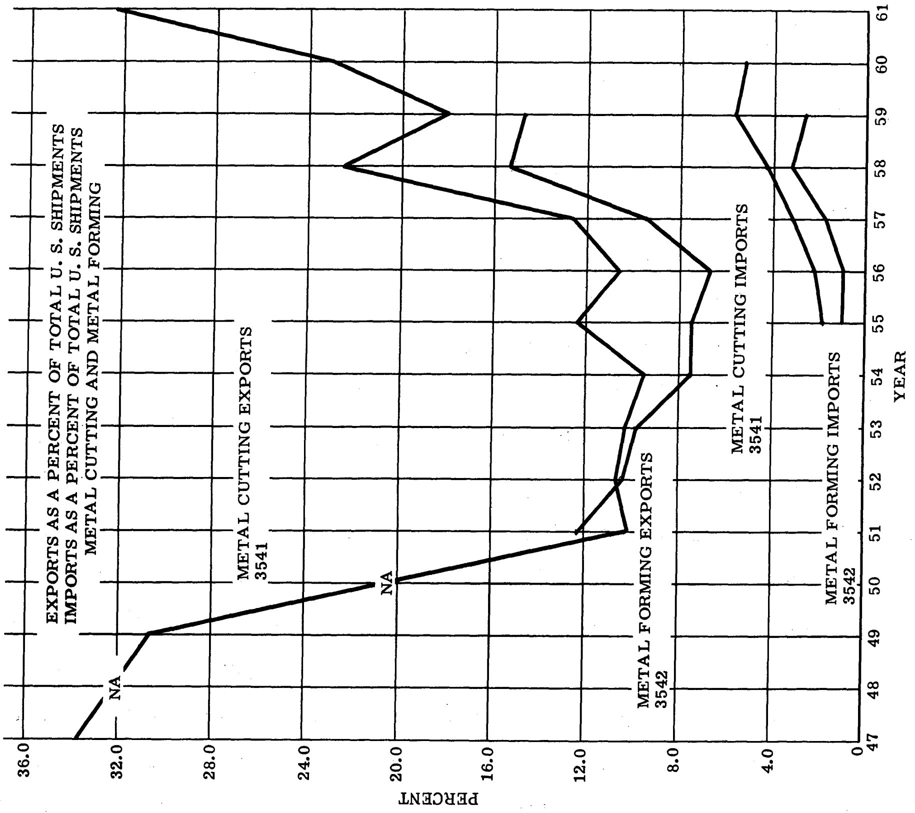


EXHIBIT 14

importer is Japan, whose imports of U.S. metal-cutting tools increased from $6.2 million to 23 million.

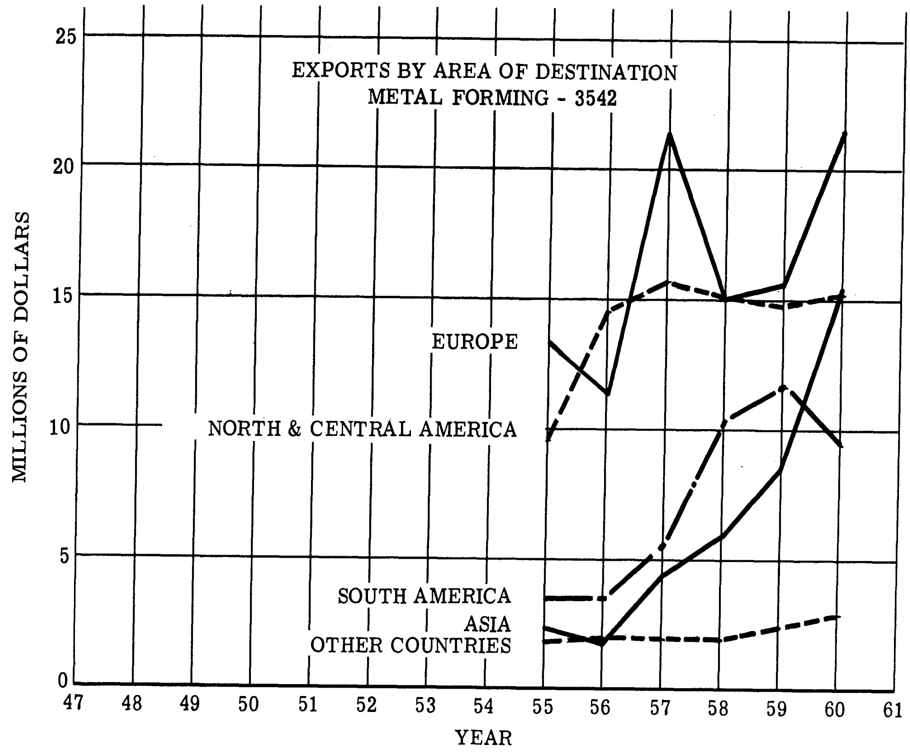


EXHIBIT 16

The United Kingdom, Germany, and Italy are the major purchasers of metal-forming tools exported by the U.S. to Europe. The U.S. imports to Canada, the major purchaser of the metal-forming tools exported to North and Central America, has remained steady at approximately $11 million per year. Japan, the major purchaser in Asia, has increased its consumption from $0.6 million to 11.9 million.

The trend of exports by major product class for the metal-cutting and metal-forming industries over the period 1954-1960 are shown in Exhibits 17 and 18. Grinding machines and lathes are the principal metal-cutting tools exported. Presses, punching and shearing machines are the principal metal-forming tools exported.

Exhibits 19, 20, and 21 show U.S. imports of metal-cutting and metal-forming tools by countries of origin for the year 1955-1960. West Germany supplied approximately 30 percent of the metal-cutting tools and approximately 55 percent of the metal-forming tools imported by the U.S. in 1960. Lathes, milling machines, and grinding machines are the principal metal-cutting tools imported. Forming machines and parts are the principal metal-forming tools imported. The impressive capabilities of West Germany as a producer of both metal-cutting and metal-forming machines are demonstrated in Exhibit 21.

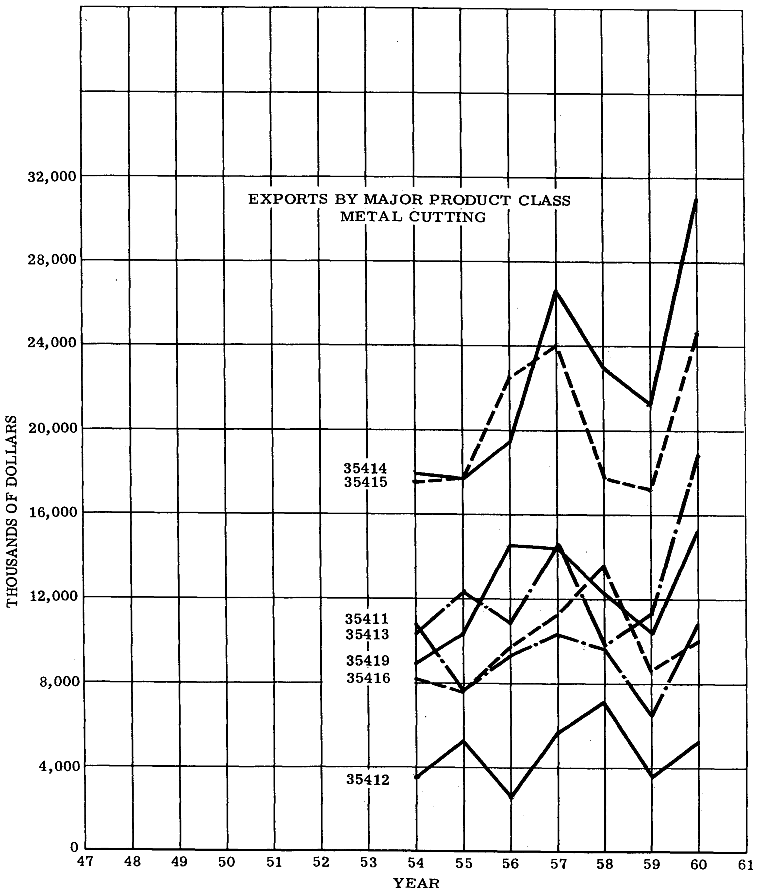


EXHIBIT 17

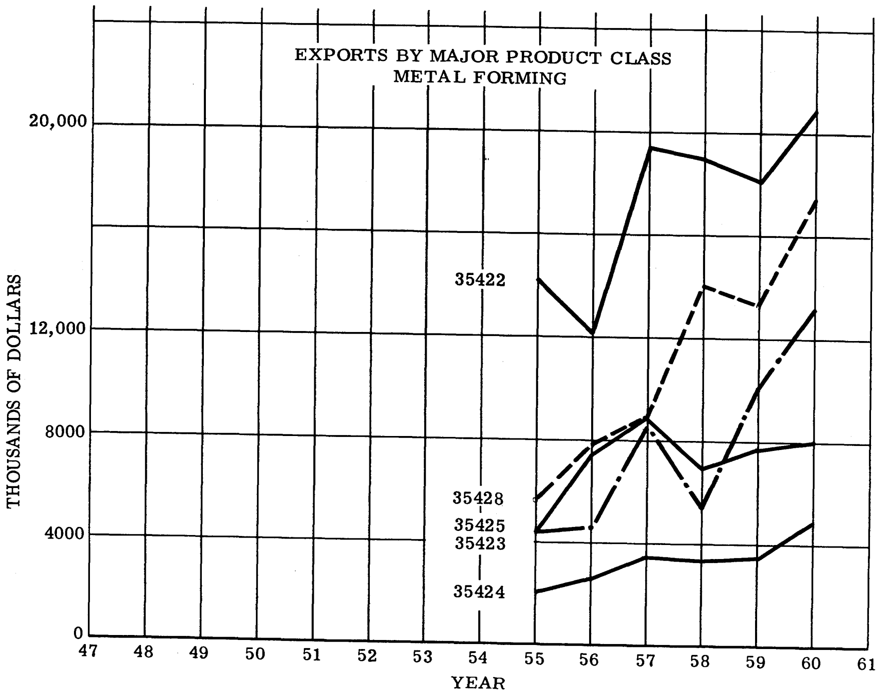


EXHIBIT 18

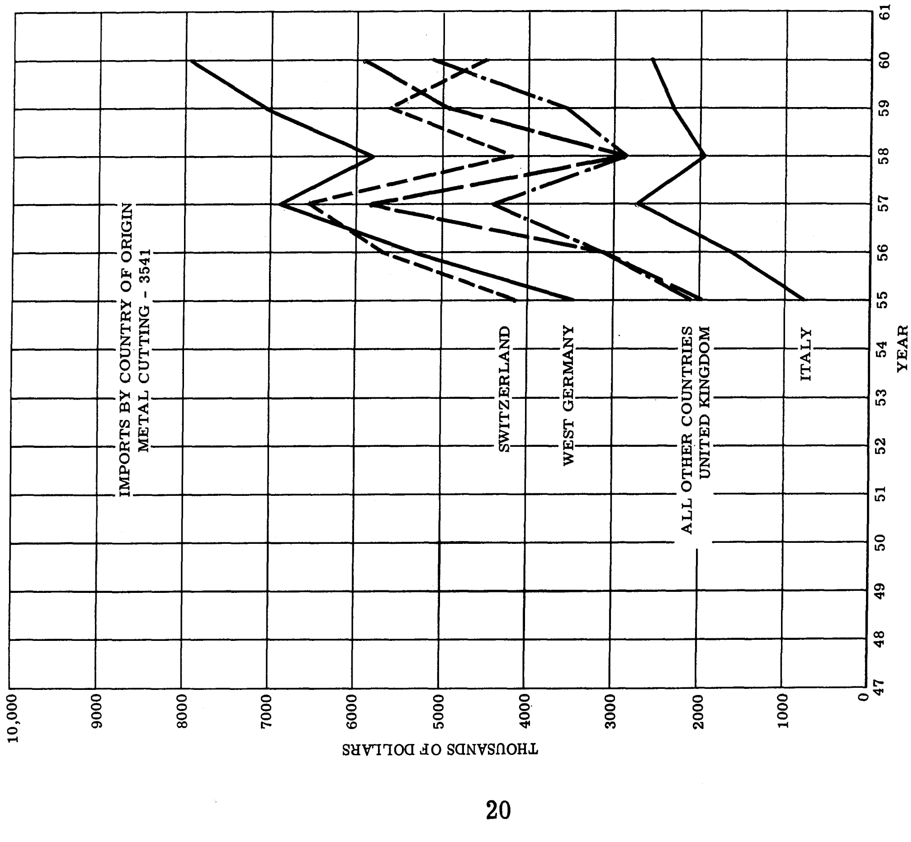


EXHIBIT 19

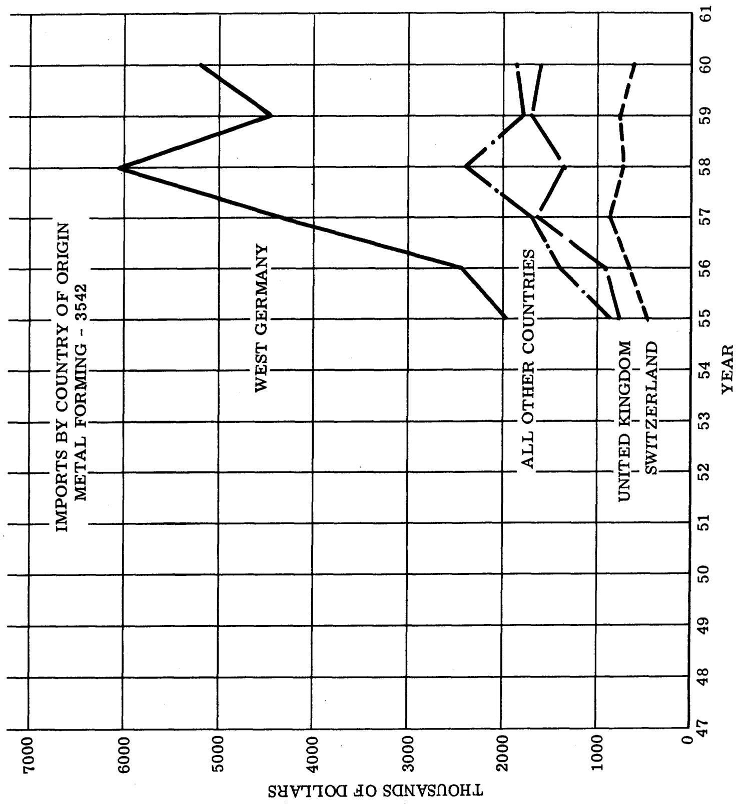


EXHIBIT 20

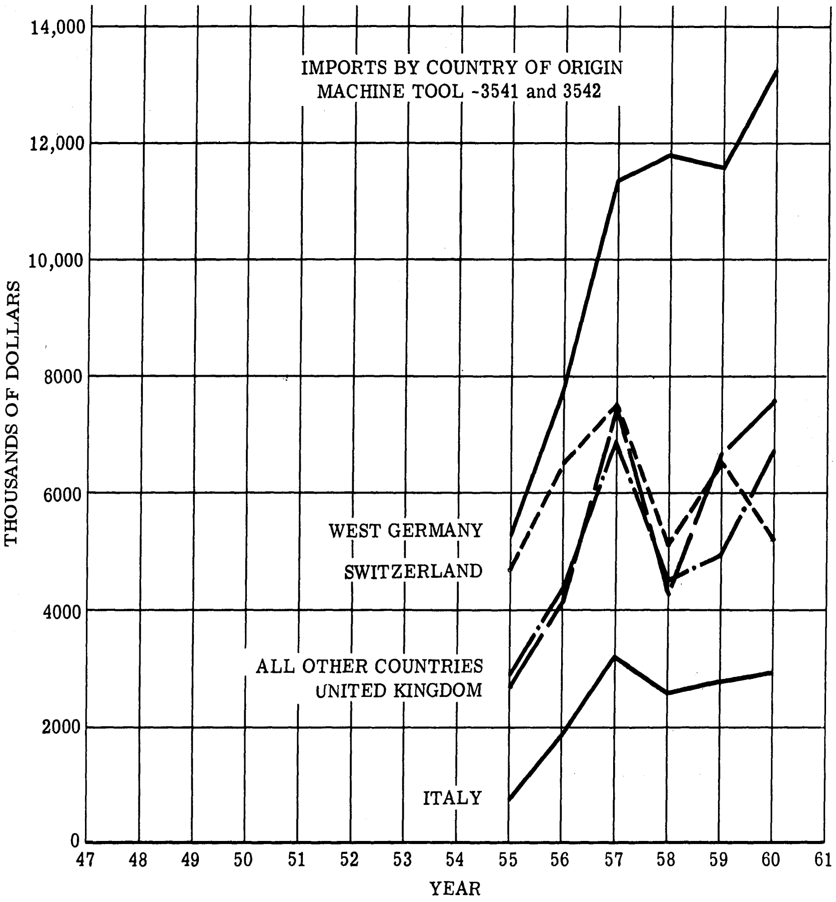


EXHIBIT 21

Although exports have been increasing for the last 2 years and are expected to be at a high level in 1962 (only slightly lower than in 1961), several important factors must be analyzed before one can conclude whether or not foreign markets will continue to receive a high percent of U.S. machine tools.

Foreign manufacturers of machine tools are operating at full capacity production; backlogs of 2 years or even more are common. Thus, the growth in U.S. export orders has been due to the great industrial expansion and growth overseas, to the inability of foreign builders to satisfy their own demands, and to the ability of U.S. industry to make quick deliveries because of low domestic demand. The low domestic demand in the U.S. is consequently of great concern. Several facets of this problem, such as modernization, investment, and obsolescence, are covered later in this report. It should be noted here, however, that imports of machine tools adversely affect U.S. manufacturers who do not share in the exports market.

As shown by the data below, hourly labor costs in manufacturing industries are considerably higher in the U.S. than in any other country.[4] This disparity accounts for much of the lag in U.S. domestic demand and also for much of its price disadvantage in foreign markets.

Country	Average Hourly Labor Costs in Manufacturing Industries (Wages Plus Most Fringe Benefits) (dollars or dollar equivalents)	
	1959	1961 (Est.)
Netherlands	.57	.66
Italy	.61	.66
France	.71	.83
Britain	.77	.85
Germany	.78	.94
Sweden	1.08	1.29
United States	2.68	2.85

Such factors as the indifference of many U.S. manufacturers and exporters to the German market and their lack of aggressive merchandising can also be cited in explanation of the state of the foreign market.[5]

There are favorable as well as unfavorable factors in the foreign picture, of course. The quality of U.S. machine tools has been amply tried and tested, and many countries are reluctant to purchase machine tools that have been produced by an untested technology and capability. Furthermore, at the present time the U.S. has certain technologies that foreign countries lack. Thus, in 1961 Germany bought $2.8 million worth of U.S.-made presses, gear cutters, and other highly specialized machines.[6]

Much light can be thrown on the general state of foreign trade and its implications for United States exports by considering the exports and imports of certain countries. For example, only 20 percent of Australia's total demand for machine tools is met by domestic production, which means that Australia offers notable opportunities to foreign manufacturers, especially as its economy recovers during 1962. Because the United Kingdom enjoys a preferential tariff, England currently supplies about 40 percent of Australia's imported machine tools, whereas the United States supplies between 15 and 20 percent. Since Australia lacks the technology and capabilities for manufacturing specialized machine tools, it offers excellent opportunities to United States exporters despite the price disadvantage. Quick delivery (3 to 6 months for the U.S. as against 12 to 24 months for foreign competitors) and adequate supplies of second-hand and reconditioned machine tools are important compensating factors.

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[4] Time, "World Business," March 2, 1962, p. 71.

[5] Machinery, January 1962, p. 124.

[6] Time, "World Business," March 2, 1962, p. 71.

Soviet bloc countries have been offering machines for export at artificially low prices, thus posing serious problems for established English, German, and American exporters. Some countries (notably Australia) are reluctant to experiment with these machines, however, because they carry no provision for adequate servicing and are the products of an untried technology.

In the past two years, certain types of U.S. machines have been exported to Russia. But export licenses are difficult to obtain at the present time, since the Department of Defense claims that our advanced technology has military value. As the technology of foreign competitors is refined, objections from the Department of Defense may lose their meaning and the Russian market for U.S. machine tools may gain significance.

In 1959, the U.S. machine tools imported by India amounted to 15 percent of its total imports. West Germany and the United Kingdom were India's principal suppliers, with 33 percent and 25 percent each.

As noted above, Japan's imports of U.S. machine tools increased significantly from 1954 to 1960. Primarily because of Japan's enormous industrial expansion, its current demands are for machine tools of advanced design or high precision performance. Although exports to Japan require Japanese import licenses, they are readily obtainable for these machine tools. Newcomers to the Japanese market can be successful, provided they convince potential buyers that the equipment is of high quality and performance. It was pointed out in a dispatch from the U.S. embassy in Japan that more business could be obtained if U.S. firms would engage in more active sales promotions.

Finally, the Common Market must be recognized as a potentially large and challenging competitor in foreign markets. At the present time its six member countries are West Germany, Italy, France, Netherlands, Belgium, and Luxemburg; and other European countries, notably Great Britain, are seeking admission. If we recall that West Germany, Great Britain, and Italy are not only the chief recipients of U.S. exports of machine tools but also the chief suppliers of machine tools to the U.S., we see how drastically their collective economic and industrial activities could affect the United States foreign market. First, these countries could, by collective endeavor, significantly increase their production capabilities through specialization of activities and intensive capital investment in plant and equipment. These increased capabilities, plus the price advantages (low manufacturing costs) enjoyed by each member country, will permit the member countries to satisfy most if not all of their own domestic demands for machine tools and to compete very effectively in other parts of the world as well. Second, the gradual abolishment of tariffs between member countries (to be accomplished by 1966) will make it much easier for them to satisfy their own demands for machine tools. Third, with the technological advances being made by West Germany and more recently by Italy, in the near future these two countries should be able to fulfill at least part of their own demands for specialized machine tools. This capability would also permit them to compete with the United States in the sale of specialized machine tools.

The extent to which other countries encroach upon U.S. foreign markets will depend on many factors—among them the extent to which low-tariff trade activities are carried on between the United States and the Common Market, the extent to which the U.S. machine tool industry advances its machine tool technology, and the extent to which U.S. firms can provide adequate demonstration of their machines, technical capabilities and aggressive policies for selling them both at home and abroad.

V. Ownership and Management of Machine Tool Companies

Metalworking firms located in the state of Michigan provide 20.4 percent of the tool metalworking employment in the United States.[7] This heavy concentration indicates how important the industry is to the economic well-being of the state. In Table VI the relative profitability of a sample of Michigan metalworking firms is compared with the total for the United States.[8]

Table VI

MICHIGAN AND U.S. METALWORKING FIRMS:
FINANCIAL RATIOS FOR 1960

Standard Industrial Classification	Industry	Profit as a Percent of Sales	Profit as a Percent of Total Assets	Ratio of Net Worth to Liabilities
Michigan[3]				
354	Metalworking[1]	2.6%	4.8%	3.13
U.S.				
354	Metalworking[2]	2.8%	3.6%	2.10
Michigan				
3541	Metal Cutting[1]	3.9%	5.0%	3.41
3542	Metal Forming	7.8	12.3	3.29
3544	Dies, Jigs, Fixtures	.5	1.1	1.27
3545	Measuring Devices	1.1	2.4	.75
3548	Other	.5	3.4	2.41

[1] All percentages from Dun and Bradstreet Data—1960.

[2] All percentages from Federal Trade Commission and Securities and Exchange Commission, Quarterly Financial Reports 1947-60.

[3] These figures represent the averages for Michigan 3541-3548.

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[7] See Exhibit 8.

[8] Data from Dun and Bradstreet reports for 46 Michigan firms were included in the analysis.

The profit of Michigan's metalworking firms as a percent of sales is 2.6 percent, compared with 2.8 percent for the United States, or about 7 percent less. However, the profits of Michigan's metalworking firms as a percent of total assets were 4.8 percent, compared to 3.6 percent for the United States, or 33 percent higher. The data indicate that Michigan has had greater sales per dollar of metalworking assets than the total industry, but has enjoyed less profit per sales dollar than the industry taken as a whole.

The SIC four-digit classification in Table VI indicates the relative profitability of each industry within the major industry group (metalworking). Although the sample represented may be somewhat biased, the information (particularly that for the dies, jigs, and fixtures industry, which represents the largest percentage of metalworking firms in Michigan) is consistent with observations and available reports.[9]

The profits of machine tool firms, in both Michigan and the U.S. at large are being affected primarily by a decline in demand. The decline in sales, from $1,386 million in 1953 to a low of $571 million in 1958, and the continued low level at $721 million in 1961, has been distressing to operations throughout the industry. Not only is the over-all rate of profit for the industry down, but many firms have actually been operating at a loss. In the machinery industry the rate of profit after taxes on stockholders' equity was 16.3 percent in 1948 and 12.6 percent in 1956; there were only two years during this period in which profits fell below 10 percent.[10] (In 1953 the rate was 9.8 percent, and in 1954 it was 8.6 percent.) More specifically, the after-tax rate on net worth in the metalworking industry has declined as follows:[11]

Year	Percent
1957	11.5
1958	2.1
1959	5.2
1960	5.3

Although Michigan machine tool firms fared slightly better than the industry average in 1960, the rate of profit for both the Michigan and the over-all industry was somewhat less than the average for all corporations. The rate of return before taxes on the net worth of all manufacturing corporations is as follows:[12]

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[9] William A. Paton and Robert L. Dixon, Make-or-Buy Decisions in Tooling for Mass Production, Michigan Business Reports No. 35, (Ann Arbor: Bureau of Business Research, School of Business Administration), 1961.

[10] Federal Trade Commission and Securities and Exchange Commission, Quarterly Financial Report for Manufacturing Concerns, available for each year beginning with 1947.

[11] Ibid. (Quarterly data have been reported for the metalworking industry since 1957.)

[12] FTC and SEC, op. cit.

Year	Corporate Assets $250,000 to $1,000,000	Corporate Assets $1 Billion and Over
1957	14.9	17.6
1958	11.4	18.3
1959	15.5	16.3
1960	11.9	19.5

It appears that machine tool firms can take two general approaches to increasing their profits: (1) expanding the market demand, and (2) lowering the costs of producing tools. Both approaches are significantly affected by research and development and the advancement of product and processes technology. The importance of technological research to machine tool firms was borne out even during the nineteenth century, for the pioneers in research and design turned out to be the most successful and long-lived.[13] At times, firms have been reluctant to adopt the newer technologies, relying instead on grotesque ornaments and gaudy color.[14] As an example, Strassmann notes that "when practical electric motors became available for powering machines in factories, several machine tool builders had to be compelled by their customers to design their machine tools so that they could be powered by such motors."

Many conditions of the last century are relevant to the present-day situation. In 1960 a survey was made of all firms reporting industrial research laboratory activity to the National Research Council.[15] A total of 69 U.S. firms reported R and D projects under machinery, machines and machine design, and machine tools. Only one Michigan firm reported research on machine tools (and this was in the area of numerical control systems for machine tools); there were three Michigan entries under machining. The projects listed under machine tools included research on:

I. Electric Controls
  a. the use of AC and DC electric motors
  b. special electric machinery
  c. electronic and magnetic circuits
  d. applications of chemistry and electronics
  e. numerical control

II. Hydraulic Controls: hydraulic pumps and control

III. Test Controls
  a. gear generating and testing equipment
  b. automatic gaging machines

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[13] W. Paul Strassmann, <u>Risk and Technological Innovation</u> (Ithaca, New York: Cornell University Press, 1959), p. 138. See Chapter IV, "Machine Tools," pp. 116-157.

[14] <u>Op. cit.</u>, p. 140.

[15] National Academy of Sciences—National Research Council, <u>Industrial Research Laboratories of the United States</u>, (Washington, 1960).

c. optical applications, mechanical and electrical phases of heavy machine-tool production

IV. Machining Operations
  a. grinding, milling and turning techniques
  b. automatic screw machines
  c. the forging, drawing, broaching, and threading of metals
  d. friction, vibration, surface finish, and kinematics, and linkages
  e. metal abraiding and precision cutting
  f. lubricants and compounds for metalworking

V. Machine Tool Design
  a. design and operation of machine tools
  b. design, development, and testing of precision machine tools, including internal grinders and boring machines

VI. Components and Accessories
  a. special tools and dies
  b. metal-cutting and forming tools
  c. gaging equipment

VII. Casting
  a. aluminum casting processes
  b. die casting
  c. heat treating of steels

(It is interesting to note that no research in H.E.R. (high energy rates) was reported.)

I. Mechanical Design
  a. balancing of rotating bodies
  b. textile instruments and controls
  c. special machines for textile applications
  d. pulp and paper machines
  e. machinery for rolling, handling, and shearing metals, particularly steel
  f. gears and gear trains
  h. converting equipment
  i. printing, typesetting, and publishing applications
  j. mechanical, electronic, and optical devices

II. Electrical Design
  a. transformer developments
  b. instrument transformers
  c. magnetic transformers
  d. electric layout and design
  e. the design of electric computers, test units, and automatic machines
  f. digital data processing and computation
  g. digital communications systems
  h. magnetic equipment design
  i. special recording instruments
  j. resistance welding processes and techniques

III. Industrial Design
  a. industrial process control
  b. systems engineering
  c. production equipment and methods
  d. custom test equipment

Forty-one industrial research laboratories listed a wide variety of R and D projects under machinability testing and machining. The three Michigan firms listed under machining reported projects dealing with foundry, forging, machining, plating and metal-coating techniques; materials used in the automotive field; propane burning equipment; production machinery; mechanical and electrochemical and sheet metal and machine shop parts.

Although it is doubtful that all companies doing research on machine tools and machinability in Michigan have reported it to the National Research Council, it is just as doubtful that adequate resources are being devoted in the state to the advancement of technology. Certainly the list of projects reported for the state is not proportionate to the list reported for the nation. Information from the National Science Foundation, which throws some light on the amount of national research being done, shows that in the machinery industry as a whole, an increasing sum is being spent on R and D.[16] Since 1956 the research performed in the machinery industry has increased 77 percent, as against 61 percent for all industry:

AMOUNT OF R AND D
(millions of dollars)

Year	Machinery Industry	All Industry
1956	$562	$ 6,538
1957	687	7,664
1958	778	8,218
1959	946	9,553
1960	993	10,497

It is hoped that the Industrial Development Research Program will make figures available on the amount of R and D being performed by the machine tool industry in Michigan and will indicate areas where technological progress is needed.

It may well be that certain levels of cooperative research will be necessary to keep the industry competitive with foreign producers. Only last June, The Economist reported that Great Britain's Department of Scientific and Industrial Research is providing 40,000 pounds annually to the Machine Tool Trades Association; the sum is to be used for machine tool research and is to be matched by private manufacturers.[17] At about the same time, the largest manufacturer in Britain announced the opening of an applied research center and the completion of a 6-year plan funded at 2 3/4 million pounds to expand its research and development facilities.

A program for cooperative research, particularly for basic research and the more costly projects, might be considered at both the national and state level. Such an

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[16] National Science Foundation, Reviews of Data on Research and Development, "Funds for Performance of Research and Development in American Industry, 1960," No. 30, NSF 61-51, September 1961.

[17] June 24, 1961, "Gearing Up British Research," p. 1401.

arrangement might make it possible for Michigan firms to gain sufficient technological capabilities to continue successful operations under today's conditions.

VI. Asset Obsolescence and Depreciation Policies

The critical state of obsolescence in this country's stock of machine tools is revealed in the estimate that 60 percent of our stock is 10-years old or older. Forty-two percent is estimated to be 10-20-years old, and 18 percent to be over 20 years.[18] This condition appears common to leading foreign competitors, whose percentages of stock 10 years or older are as follows: Britain, 50%; France, 59%; Italy, 56%; and West Germany, 55%. Moreover, the productivity in machine tools has been greatly increased since 1950; it is estimated to be about 40 percent and can be attributed largely to improved design.[19] The use of advanced technology, the greater unit output of the newer machines, and a significant improvement in tolerance capability are all factors which have tended to increase productivity.

The high degree of obsolescence of capital equipment and machinery is by no means limited to machine tools. For example, a recent British survey determined the following ages for industrial equipment:

Table VII

PERCENT OF INDUSTRIAL MACHINERY
AT LEAST 10-YEARS OLD

Industry	Percent
Industrial Engines	41
Aircraft Manufacturing	47
Consumer Durables	53
Electrical Machinery	56
Automobile Industry	57
Construction Industry	59
Agriculture Industry	60
Machine Tool Industry	63
Textile Machinery	75
Shipbuilding Industry	87

A similar stock of old assets is presumed to exist here in the United States. With most of our major capital assets in an advanced state of obsolescence, we have a vast potential market for modernizing and replacing machinery and equipment of all types,

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[18] Business Week, "Britain's Over-Age Machine Tools," January 6, 1962, pp. 42-3. As stated in The United States Industrial Outlook For 1960, "A McGraw-Hill survey in 1959 disclosed that more than 72 percent of the 2-1/4 millions of machine tools in American industries are over 10 years old." Also, see American Machinist, "Metalworking Manufacturing Figures," 1958.

[19] From a survey of machine tools by Metalworking Production in Britain, quoted in Business Week, January 6, 1962, pp. 42-3.

including machine tools. The similar situation in such countries as Britain offers a potential market for exports, provided the U.S. undertakes a program of productive modernization.

What factors account for the obsolescence of our major capital assets? Many can be named; among them are the inability to secure adequate debt and risk capital, the excess capacity generated during World War II and the Korean Conflict, and the fact that during the past few years general business conditions have been at a level that did not allow adequate new investment programs to be undertaken for the future. Moreover, it has been asserted that high rates of taxes on corporations and the absence of "realistic" methods of tax depreciation for determining taxable income are crucial deterrents to capital investment.

With the personal support of President Kennedy, the current Administration is endorsing two approaches to the modernization of our industrial equipment. These approaches consist of (1) a revamping of Bulletin "F", which establishes the anticipated useful lives of more than 5,000 items of capital equipment, and (2) the granting of a tax credit of up to 8 percent of new equipment purchases. Criticism of federal depreciation policy has been long and intensive. With increasing competition for foreign markets and an increasing encroachment of imports on domestic production, the cry from industry and interested parties has reached new heights. Relief will come only through a revision of federal policies—certainly an appropriate step in view of the statement by Dan Throop Smith, consultant to the Treasury, that "Our depreciation allowances have been the stingiest in the world."[20]

Past criticism of Internal Revenue practices regarding depreciation policy was that owners were not allowed to write off their assets fast enough. The Internal Revenue Code of 1954 did much to correct the rate of write-off by instituting certain accelerated methods, such as declining balance and sum-of-the-years digits methods, and multiple rates. A critical factor in the amount of depreciation allowed—the estimated lives of various assets—remained unchanged, however, and Bulletin "F" was left much as it was written in 1942. Many critics contend that the useful lives suggested in Bulletin "F" are based largely on physical life (an outdated one at that) and were formulated according to experiences in the 1930's, when the replacement of machinery and equipment was severely lagging. Critics also charge that technological obsolescence of assets and shortened lives have never been fully considered; as the pace of technological advance accelerates, this point gains in importance.

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[20] Wall Street Journal, "Treasury's Overhaul of Depreciation Rules to Bring Tax Relief," March 2, 1962.

Criticisms such as these have prompted the Treasury Department to launch engineering studies in six major industries: aircraft, automobile, electrical equipment, machine tool, railroad, and steel.[21] An engineering team was formed to study the obsolescence of assets in each of these industries by actually observing plant operations and inspecting plant records of the purchase and retirement of machinery.

As a result of the studies, in October 1961 new equipment lives were issued for the textile industry; the composite life of 25 years in the 1942 edition of Bulletin "F" has been reduced to 15 years. The Treasury hopes to have similar revisions for the other five industries ready by May or June of this year. The reduction in useful lives is expected to be about 25 percent; since the composite life of machine tools is now 17-20 years,[22] the new write-off period should therefore be about 12-15 years.

The new revision should also provide for more frequent negotiation between corporations and the IRS. Between 60 and 70 categories of industries are being substituted for the more than 5,000 items listed in Bulletin "F", and 4 to 5 classes of equipment will be designated within each industry. In addition, broad classes will be established for items commonly used by all companies, such as office equipment and vehicles.

It is expected that a reform in depreciation tax policy will aid the machine tool industry not only directly (by reduction in federal income taxes), but indirectly as well. If, as is hoped, the program stimulates modernization and the expansion of general capital assets, the machine tool industry will benefit from an increased market demand for its products.

A depreciation tax credit of up to 8 percent on most equipment purchases was first proposed to Congress by President Kennedy on April 20, 1961. Since then the House Ways and Means Committee has spent considerable time discussing and studying the original proposal, which called for a tax credit of 6 to 15 percent on new investment, depending upon its relationship to depreciation allowances. Early this month the Committee was giving final consideration to tax legislation that would allow a straight 8 percent credit on all qualified purchases of new equipment. The above-noted revision of Bulletin "F" should be ready for release this spring. And it appears likely that legislation will be completed allowing for a depreciation tax credit to all industry. Both of these measures may be expected to have a direct effect in increasing the funds available for machine tool investment programs, and an indirect effect in increasing market demand from general industry stimulation of capital replacement and expansion expenditures.

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[21] The Journal of Accountancy, "Dillon Reports Treasury Depreciation Surveys," March 1962, pp. 9-10.

[22] United States Treasury Department, Internal Revenue Service, Bulletin "F"; Tables of Useful Lives of Depreciable Property, Washington, 1942, p. 38.

VII. Outlook of the Machine Tool Industry for 1962

Several factors other than depreciation revisions and a possible investment tax credit point toward a more favorable business outlook in 1962 than 1961. The effect of these favorable factors was already being felt in the fourth quarter of 1961, as noted in Exhibit 2, when metal cutting sales were $150,000, the highest quarterly figure since 1957.

Total exports of metal cutting and metal forming, $275.8 million in 1961 or about 32 percent of all shipments, are expected to fall somewhat in 1962, but the expected level will still exceed all prior years by a significant amount.[23] The improved business conditions abroad, the large stock of obsolete equipment in other countries, the generally acknowledged superior quality of U.S. machines, and the foreign competitors' continued lag in delivery time will all contribute to holding exports to about $250 million this year. Unfavorable factors to be watched are the relatively higher costs of American machines (30 to 60 percent above European prices), the trend for European technology to approach ours, and a gradual decrease in foreign competitors' delivery time. Imports of foreign machine tools to the U.S. are estimated to be slightly higher in 1962 than in 1961, rising from 30.9 million to 34.0.[24] These estimated imports will account for a slightly higher percentage of total machine tool sales in 1962 than they did in 1961 (4.4 versus 4.3 percent). However, it is expected that the increase will be restricted to metal-forming tools; metal-forming imports are expected to move from 4.3 percent of total sales in 1961 to 4.9 percent in 1962, or from $9.5 million to 10.5 million.[25]

At the close of 1961, new orders for both metal cutting and forming were higher than the average for 1960, with net new orders of $44 million for metal cutting and $13 million for forming. The 1960 averages were $42 million and 12.5 million respectively. The backlog of metal-cutting tools at the beginning of this year was 5 months, the highest backlog carried over to a new year since 1956.[26] Far fewer orders were being cancelled at the end of 1961 than earlier in the year; December cancellations amounted to $1,750,000 as compared with $3,100,000 in January. Total domestic order cancellations declined from $37,150,000 in 1960 to $25,800,000 in 1961.

An improvement in general business conditions is strengthening the domestic demand for machine tools. The gross national product is estimated to reach $560-70 billion this

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[23] United States Department of Commerce, Business and Defense Services Administration, Metal-working Equipment Division, "Machine Tool Industry: Outlook for 1962 and Review of 1961," January 22, 1962, p. 3.

[24] United States Department of Commerce, "Machine Tool Industry: Outlook for 1962 . . ." op. cit.

[25] Op. cit.

[26] U.S. Department of Commerce, Office of Business Economics, 1961 Supplement to the Survey of Current Business, May 1961, pp. 166-7.

year, an increase of 7.4-9.3 percent from last year's record high of $521.3 billion. Business outlays for plant and equipment are currently estimated at $37.2 billion for this year, a record high for industrial investment and 8 percent above the 1961 figure of $34.4 billion.[27] The aggregate index of industrial production reached its highest peak on record in December, when 115 (1957 = 100) was reported by the Federal Reserve Board. The machinery industry is enjoying a nearly proportionate share of this gain, with an operating index in January of 111 (1957 = 100) compared with 114 for all industrial activity. As a result of this volume of activity, machinery manufacturers have been among the heavy borrowers of bank funds in the New York area. Although some business indicators slowed down slightly in January—average hours worked weekly in factories (to 40 from 40.4), annual rate of housing starts (to 1,292,000 units from 1,309,000), and the annual rate of personal income ($430.3 billion from $431.8)—such declines are considered normal in the second year of business expansion. Past patterns indicate that industrial activity will increase throughout the year. The favorable rise in corporate profits is seen by many as the key to increased capital spending. Profits of 530 companies in 30 different industries surveyed by the Wall Street Journal for the fourth quarter of 1961 were up 22.5 percent from the previous year.[28] Although the indicated national figures for the fourth quarter were at a record rate, second only to the last quarter in 1950 (induced by the buying scare early in the Korean War), profits this quarter are estimated to be even higher. Twenty-five machine tool companies reported quarterly profit increases of $3.7 million (17.6 percent) in the last quarter.

Nearly all factors point toward an improved outlook for machine tools in 1962. The unfavorable factors, such as the slowing down of exports and the uncertainties over capital investment programs, must also be considered; but the estimates of the Department of Commerce that 1962 sales will exceed 1961 sales ($721 million) by 6 percent appear to be justified.

Although domestic demand may be expected to increase slightly during this year and in future years, there is a serious question whether the machine tool industry can maintain its competitive position in view of rising costs and the rapid emergence of strong foreign competition (discussed more in the following paper). New product development founded on increased research and development expenditures may very likely be the answer to the future success of the industry. This is the focus of the present Industrial Development Research study of the machine tool industry.

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[27] Wall Street Journal, "Business and Finance," March 13, 1962. Information was supplied by Commerce Department and the Securities and Exchange Commission from its survey conducted in January and February, 1962.

[28] Wall Street Journal, "Corporate Earnings Set Record for Peacetime, Likely to Widen Gap This Quarter," February 28, 1962.

2

TECHNOLOGICAL TRENDS IN THE MACHINE-TOOL INDUSTRIES

Alfred O. Schmidt

Until recently, studies involving the processing of engineering materials were seldom part of the research program nor were they included in engineering curricula in most American universities. There are a few exceptions, like the University of Michigan. It is true that some engineering colleges had "shop courses" which taught the rudiments of machine operation—theory being neglected primarily because few of the ideas had been proven in a scientific way. Few scholars turned their attention to the subject, because historically the developments in the processing of materials were empirical in nature. Not only did the scholars think the solution to these problems was of a non-academic nature, but the machine-tool and production-engineers also were satisfied that better processing could be attained only by trial and error methods.

The prospect of creating new materials is fascinating to engineers, but equally challenging is the processing of these new materials. For example, in the production of missiles the machining and processing of the component is still mostly done by tool-room methods. New techniques must be developed to permit faster and less expensive operations.

There are two main forces at work that will require the solution of these problems by our machine-tool engineers. The first and most urgent is our world position, dependent on our national economy and security. It is known that in England, Germany, Russia, and other countries, research associations have been set up to solve machine-tool problems. Success in any one of these organizations can more or less affect our productibility in comparison with our competitors. Two Russian research institutes for machine tools, one of which has a staff of 4,000 and the other more than 2,000, were described in a recent issue of "Machinery". Of course, these figures include shop employees who build experimental machines, but the article emphasized that the majority of the employees were technicians, designers, and higher-grade research workers. It was further pointed out that these were but two of many similar centers for industrial research in Soviet Russia. The second force that will necessitate our finding the solution to these problems is economic. We need to develop more efficient machine-tool operation. Less waste in the processing of some of our scarcer, higher-priced materials will be required. Most important of all will be the need to produce parts at a higher rate with greater reliability, closer tolerances, and lower man-time per part. This will be necessary not only to meet our own competition, but also to meet the competition that eventually will come more strongly from abroad.

The solution to these and many other related problems lies in cooperation between universities, government, and industry at large. This cannot be accomplished by the establishment of one giant research center, but rather by the development of many centers throughout the country which are well staffed with both technicians and researchers. A word of caution: many small "one-man" centers will also be ineffectual. There must be several centers of a substantial size so that teamwork and cooperative planning will be effective.

Presently, in European universities, one finds teaching and research progressing in machine-tool design and in machine-tool operation. The effort is directed to standard and special machines and to attachments and accessories as well as to high-precision machines. In the latter area the problems of vibration are most critical. One also finds courses taught on the theory of metal cutting. These include the study of the machinability of materials, tool wear, lubrication, cooling, and servo-mechanisms. The influence of friction and temperature is studied. Certain aspects of the solid state as well as metallography and crystallography of the workpiece are investigated. With regard to the newer materials, little is known about machinability or even about what problems actually do exist. Students in the laboratory learn the use of standard and high-precision instruments for the measurement of lengths, angles, surfaces, etc. These are covered in courses in metrology. Students in the universities take courses in automatic control. This particular area is already highly developed in both Europe and America. It is best understood by a sound mathematical approach. Most American colleges teach this subject in courses entitled Theory of Automatic Control or Servo-mechanisms. Courses in statistics and quality control are also offered both here and abroad and have a close relationship to the functions of the machine-tool engineer. Closely allied to the technical courses listed above are courses in management and in industrial economy.

Cooperating also with the institutions of higher education are some of the associated industrial research laboratories. A brief description of the laboratories occupied by P.E.R.A. at Melton Mowbray, Leicestershire, follows: The building provides 45,000 sq. ft. of floor space and cost $700,000. The equipment it houses is worth over twice as much. Much of the space is devoted to production methods in the metalworking industry. Among other things, they are investigating the effects of vibration on machines and cutting tools. Research on the impact extrusion of steel and non-ferrous metals extends into the study of properties of workpiece materials, slug lubrication, and variations in extrusion pressure with percentage reduction in area. Much of this work is carried out on fairly large components using a 100-ton, single-action, eccentric press. In the machine-tool laboratory, investigations are taking place in the various aspects of slideway lubrication. There is also a well-equipped metrology laboratory which is completely insulated from the rest of the building to eliminate the chance that vibrations might be transmitted from the adjoining workshops. There are also metallurgical laboratories which conduct chemical analyses as well as work in metallography. In addition to general investigations, some 1200 special problems were investigated during the first six months of its operation.

Our universities have the scholars capable of doing the job required in this country. However, they cannot do it alone. They need the cooperation of industry to be most effective. They have to know what problems industry faces in today's production; they also will have to call on industrial experience from time to time. They may ask industry to train some of the young investigators and they will need financial help. The universities working with industry as a team will be in an excellent position to provide the scientific knowledge necessary to keep American production second to none.

Machine-Tool Developments

In all countries of the world exist increased demands for industrial and consumer goods which have created a greater market for machine tools and related production equipment. We find, therefore, today, well-established machine tool factories in countries which 25 years ago imported most of their machine tool needs. The mass market of the United States traditionally fostered rapid machine-tool developments within its own borders, and the same type of industrial development unfolds at this time in other parts of the world, e.g., the European Common Market, Russia, and Japan.

Traditionally, Great Britain has had a well-established machine-tool industry to supply its own factories as well as those of the empire and of many other countries. Germany, Switzerland, and Sweden also for many years have had a flourishing machine-tool industry competing with the U.S.A. and Great Britain in the world markets. Since the end of World War II, France, Italy, Belgium, Holland, Denmark, and Austria have made new and vigorous strides in the field of machine tools. The same may be said of Russia, Czechoslovakia, Hungary, Poland, and China. Here is a quotation from a recent Czech government publication in the field of heavy industry:

> Czechoslovakia's share in the world export of metal-working machine tools represents today some 10 per cent. Czechoslovak machine tools, exported by the Czechoslovak foreign trade corporation of Strojimport, are of great help in ensuring the industrialization of Latin-American countries. Especially in Brazil, Argentina, and Mexico the partners of Strojimport have had the opportunity to convince themselves of the advantages of Czechoslovak machine tools of the TOS, MAS, SKODA, and other makes.

Another country which produces various kinds of precision machine tools for its own markets and for export is Japan.

For a long time many of these countries had machine-tool factories which provided machinery for some of their production needs, but these have been greatly expanded during the last ten years, benefiting from the world-wide expansion of machine-tool requirements. They not only compete in their own countries but also in the world market. These developments created, as never before, a competitive challenge to the more established machine-tool-producing countries. The increase of industrial production in Western Europe compared to 1938 is 60 per cent; a similar increase is noted in Japan. In reflecting upon the fact that machine tools are the basic machinery for almost all industrial activities, and a prerequisite for any attempt to increase productivity, it is not surprising that machine-tool industries have grown or sprung up in almost all countries. India has created a number of machine-tool manufacturing facilities; numerous Indian engineers are in training in machine-tool factories in other countries, and the new Institutes of Technology as well as other Technical Faculties are teaching production techniques and machine-tool engineering.

In the U.S.A., there has been a trend for at least 30 years toward automatic machine tools to be run by operators who have had little experience or training. Machine tools in other countries were mainly built by expert craftsmen for use by craftsmen. This situation has changed in recent years and most machine-tool developments are aimed at a dual goal of operation as automatic as possible and yet as simple as possible, so that it is not necessary to train a person for many years before he or she becomes an efficient machine-tool operator.

A very good survey of machine-tool developments could be obtained from the machines presented at the Machine-Tool Show in Chicago in 1960, the Soviet Exhibition in Mexico City in 1960, the Leipzig Fair, the 1961 Industrial Fair in Toronto, and the Machine-Tool Exhibition in Brussels. The common tendency to make general-purpose machine tools more automatic was very obvious. The trend also is away from large, single-purpose machinery and toward specialized machines with transfer mechanisms which can be adapted to a variety of workpieces. In a class by themselves are the tape-controlled universal machines, which have been developed for the machining of workpieces which do not fall into the mass production classification. These machines can be operated without expensive fixturing. A variety of tools are often available through an automatic tool-changing mechanism. The controls for automatic setting of position and depth eliminate the need for extensive markings on the workpiece.

While the developments primarily in the field of metal-cutting or chip-making machine tools have been dealt with here, it should also be mentioned that other types of machine tools have come more into use and have gone through a similar development. Forming, shaping and pressing metal parts to high accuracy, often completely automatically, is another feature of present-day engineering production.

Machines for the production of screws and gears by cold forming are quite common today. European production of these types of machines now approaches the same tonnage as that of metal cutting machine tools, although one must remember that presses, die casting machines, and cold forming machines are usually of very large dimensions.

Machine-tool developments in the U.S.A. are usually quite well known and widely publicized. The following discussion of various representative European, Japanese and other machine tools will illustrate some of the current features and design trends abroad. In many cases they present new features, in others some similarity to American equipment.

The jig boring machine in Fig. 1 can be operated manually or by an automatic control system. The design of the machine is based on the above considerations. Its construction is stiff with asymmetrical columns placed close together. Its playless belt transmission drive has no gears in the high-speed range; see Fig. 2.

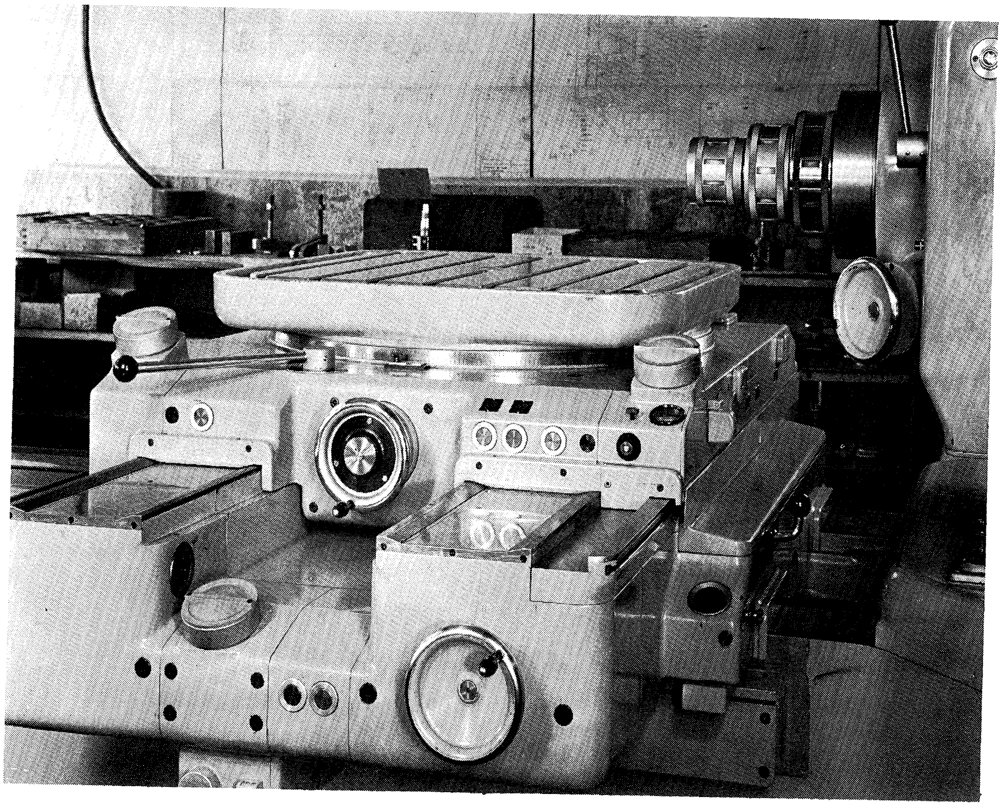

Fig. 1. Jig Boring Machine DIXI 3S for Optical or Automatic Positioning. Made by DIXI S. A. Le Locle, Switzerland.

The automatic control system can be used at will. It therefore rests with the operator whether the required positions are to be set by means of the optical screens, or whether they are to be selected automatically, either direct to the nearest thousandth of a millimeter (five

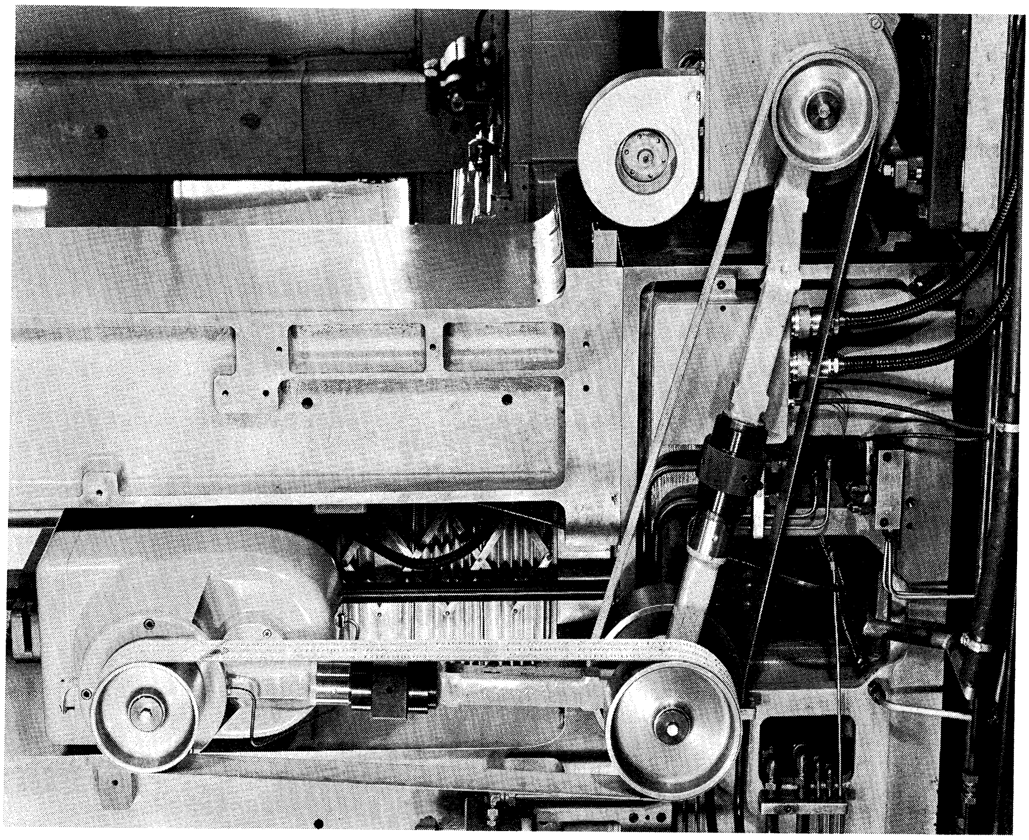

Fig. 2. Belt Drive of DIXI 3S Jig Boring Machine. The two pulleys are kept apart by adjustable pressure rods. Speed ranges can be altered by changing two pulleys.

hundred thousandths of an inch) by pressing a series of keys, or by working with a perforated tape. If he decides in favor of the tape, it can be perforated automatically by preselecting the various operations by means of the keys, thus without much loss of time.

The depth adjustment (boring-feed, setting for milling or surfacing) is effected only by means of the table, i.e., the machine has no longitudinal spindle-adjustment. The length of the tool (distance between the tip of the tool and the main bearing) remains constant during operation. This minimizes vibrations and produces accurate cylindrical bores. Operation is simplified by the small number of levers and hand-wheels with safety interlocking functions.

A universal gear shaving machine is represented in Fig. 3. Shaving can be adopted in place of gear-tooth grinding, and it can take place immediately after gear-cutting and without intermediate operations. Gear shaving is based on the use of a rotary cutter in the form of a spur or helical gear, the flanks of which are cut parallel to the profile. Shaving does not require tooth surfaces which are accurate from previous machining operations. Controls for all the operations are enclosed in the knee, which supports the rotating subplate intermediate

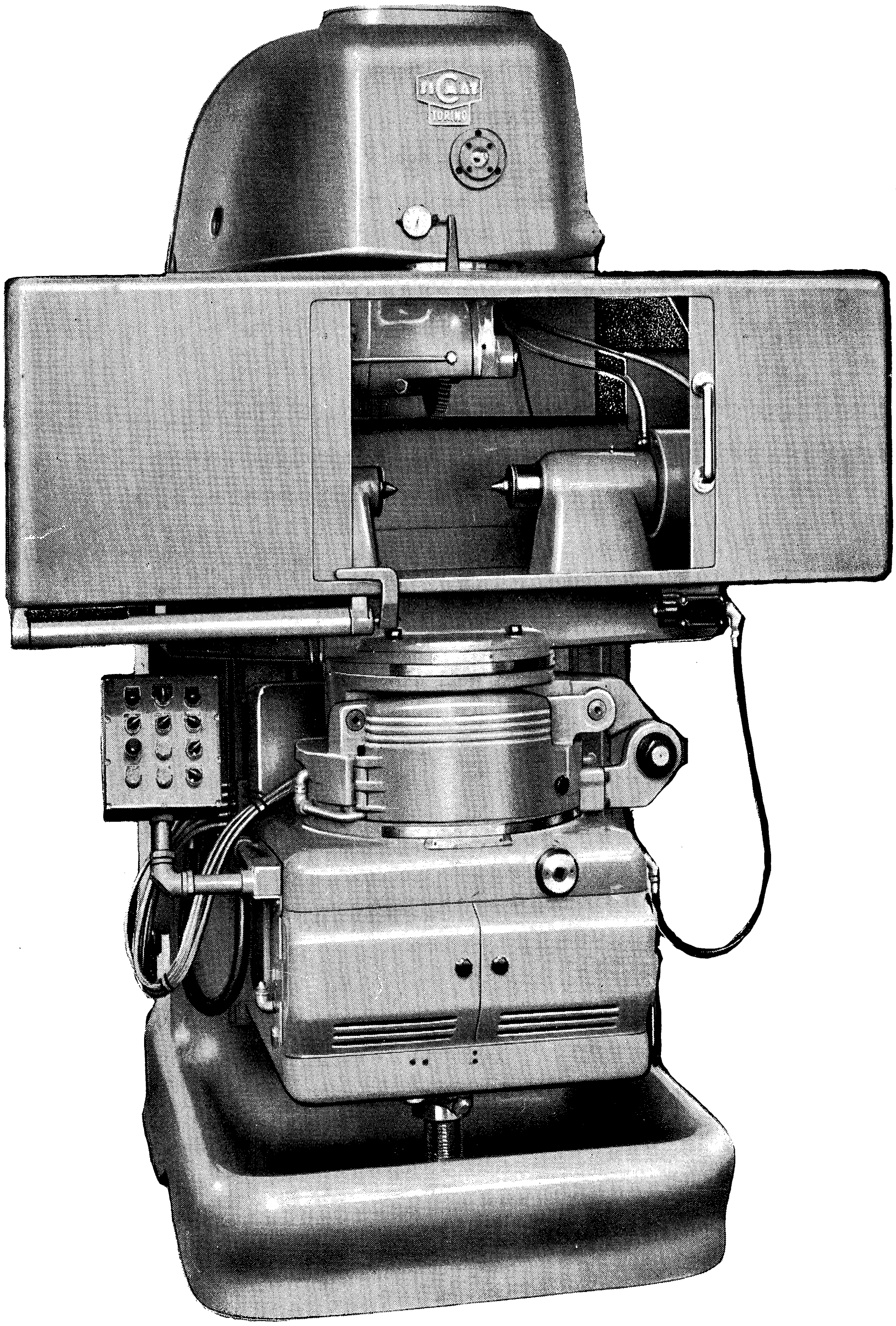

Fig. 3. Universal Gear Shaving Machine. Made by Sicmat, Turino, Italy.

slide, rocking table for crown-shaving, and work-table. The work-table rotation is independent of the slide position. The shaving-tool is mounted in the cutter-head and is movable about its vertical axis. It is precisely adjusted by means of a Vernier scale, and for micrometrical displacements a microdial indicator is used. Head setting angles are checked by means of Johansson gauge blocks. This enables the operator to obtain exact duplication of the setup.

Illustrated in Fig. 4 is a wet grinding machine for grinding flat surfaces on cylinder blocks, manifolds and cylinder heads for passenger car and diesel engines. This machine can also be adapted to the usual functions of a surface grinder by mounting a special table with magnetic chuck on the base. A 4-hp motor drives the grinding wheel; separate motors are provided for the wheelhead traverse and the coolant pump. Automatic feed reversing is effected by means of an electric switch and adjustable stops on the horizontal crossrail and carrier.

Japan has developed a machine-tool industry in conjunction with the recent growth of her industry. The amount of machine-tool production in Japan is surprising. It has been achieved both by cooperation with foreign companies and through Japanese initiative.

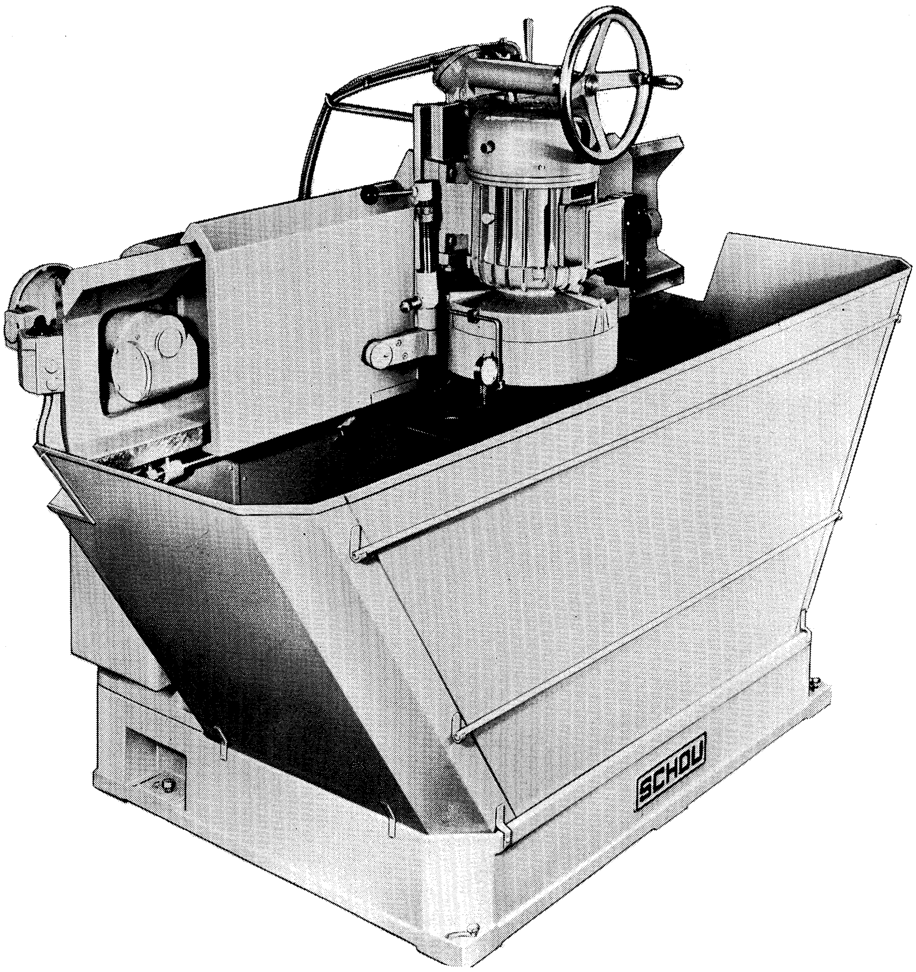

Fig. 4. Automatic Surface Grinding Machine. Made by Schou and Company, Copenhagen, Denmark.

The following is a brief survey of recent representative Japanese-developed machine tools.

The lathe shown in Fig. 5 is a highly accurate, compactly designed, rigid high-speed lathe, with simple controls. A sturdy, quill-type spindle unit is mounted with two pressure-lubricated, high-precision antifriction bearings and one thrust bearing. With a 2-pole change motor and a Kopp variator, stepless spindle speeds are variable over a wide range, i.e, 25 to 4000 rpm, and the speed is indicated by a tachometer in the headstock. Without the use of any change, gear, inch, metric, DP, and module threads can be produced by operation of levers alone. There are 32 feed rates, and power feeding of the carriage is instantaneously controlled by a drop worm mechanism and an automatic feed stop. A hydraulic copying attachment is available for this precision lathe for copy-turning operations.

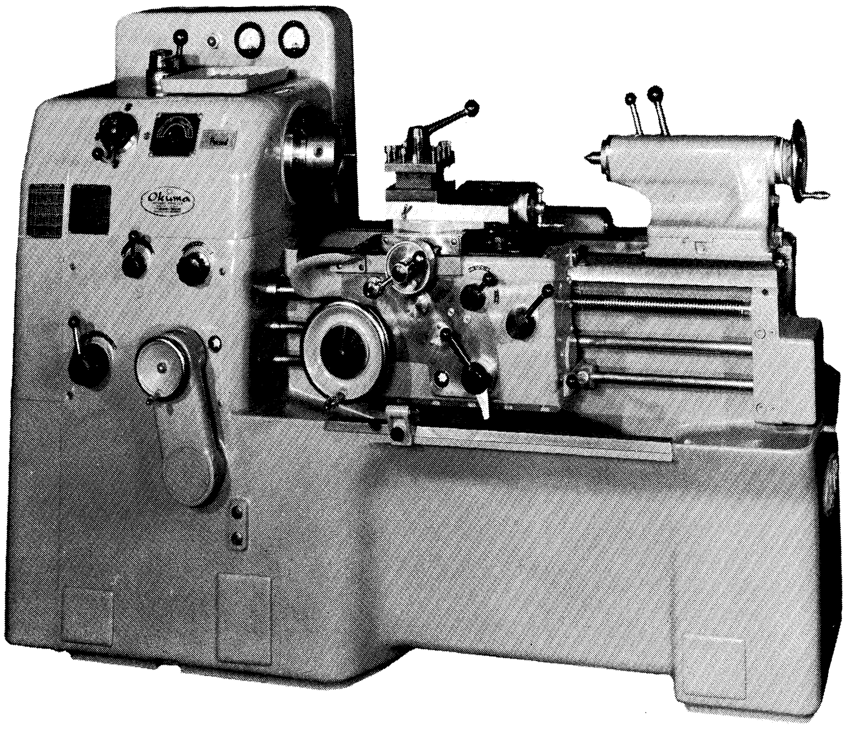

Fig. 5. High Speed Precision Lathe, Model LP, by Okuma Machinery Works, Ltd.

A camless chuck automatic turret lathe is shown in Fig. 6. The point at which machining is terminated can be selected at will. Accurate feeding is given by a feed mechanism combining hydraulic power and gears. Mechanical feeding is also possible with a lever handle, and tool setting is very easy. The turret head can move back to an optimum position suiting the product machined. Spindle speeds from 57 to 2000 rpm and feed rates from 0.05 to 1.14 mm/rev (0.002 to 0.04 ipr.) can be changed during machining through control of an auxiliary drum.

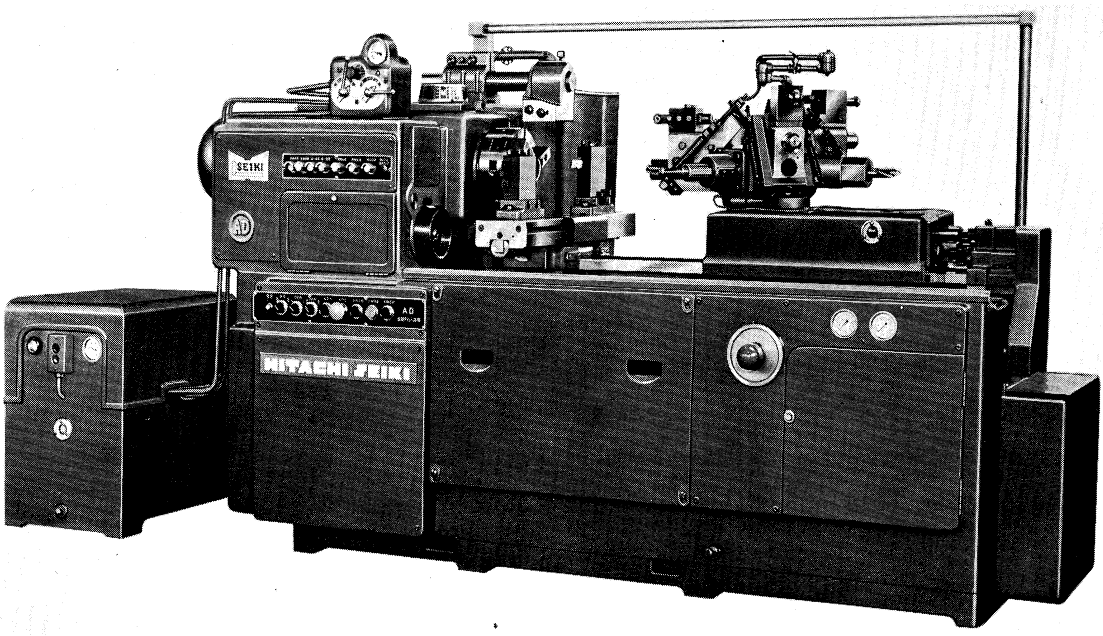

Fig. 6. Automatic Turret Lathe, Model AD, by Hitachi Seike Company.

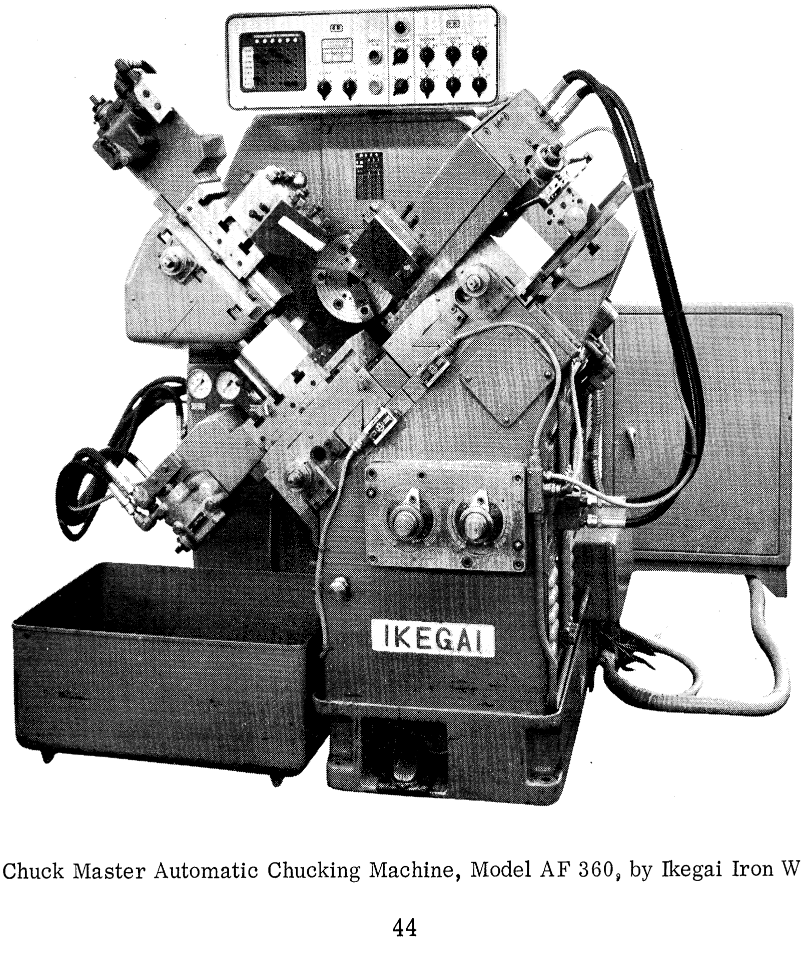

Fig. 7. Chuck Master Automatic Chucking Machine, Model AF 360, by Ikegai Iron Works, Ltd.

The automatic chucking lathe, Fig. 7, is built according to the "building block" concept and is available in many variations. Any selection or combination of three types of tool slide, such as turning and facing, facing and plunge cutting, and copy turning, can be made. Boring and drilling can also be done. These slides operate by electro-hydraulic power with steplessly variable feed rates of the spindle. The sequence of operations performed in this automatic machine is easily selected simply by inserting plugs into sockets on a control panel.

Copy milling operations in one, two, or three dimensions can be performed with a tracer head, Fig. 8, by hydraulic power. In the case of the copying operation in one direction, the feed rate of the table is regulated by the inclination angle of the master. The optimum type of

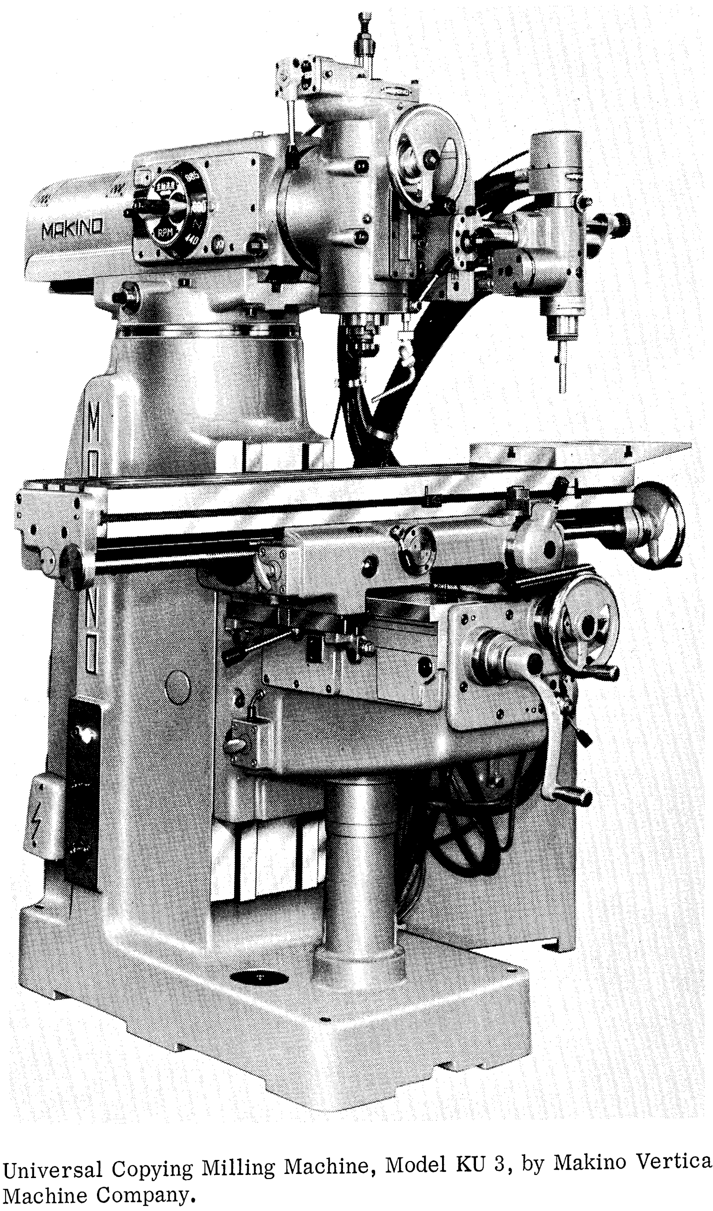

Fig. 8. Universal Copying Milling Machine, Model KU 3, by Makino Vertical Milling Machine Company.

copying operation (dimension) can be selected according to rough or finish machining and the shape of the machined product by setting the machined part just once. Spindle speed is 225 to 4000 rpm. Feed rate is stepless.

The machine in Fig. 9 is designed for boring and drilling operations on small products. Setting can be made in rectangular coordinates with two standard scales installed on the table and the slide. These scales are projected and enlarged on screens by means of an optical lever, and the operator can measure these scales up to 0.001 mm (0.00004 inches). The error

Fig. 9. High Precision Jig Borer, No. 0, by Mitsui Precision Machinery and Engineering Company, Ltd.

of positioning is guaranteed within 0.002 mm (0.00008 inches). The spindle rotates on roller bearings of high accuracy and speeds are infinitely variable between 20 and 3000 rpm. The amplitude of vibration of the rotating spindle is within 0.002 mm (0.00008 inches). Since the spindle quill is well balanced, it can be smoothly traversed up and down by means of a lever, and even a light shock during operation can be sensed by the fingers of the operator. Holes of 0.04 mm (0.0016 inches) and 0.4 mm (0.016 inches) minimum diameter, respectively, can be drilled or bored.

A semi-universal type high precision and production grinder for precise mass production of machine parts is shown in Fig. 10. A cam in-feed mechanism is adopted for this grinder for the purpose of producing equal-sized and finely finished parts. It is equipped with an automatic sizing device. Rapid, coarse, and fine feeds, sizing, and spark-out can be performed automatically, and cyclic operation is controlled by a single lever. Wheelhead and table can be swiveled to grind tapers and angles. Work speeds are steplessly variable and can be adjusted automatically to suit rough or fine finish grinding. A wheel truing unit is located at the back of the wheelhead, and a wheel wear compensator keeps the position of the work relative to the wheel unchanged, in spite of a number of truings. The wheel spindle is

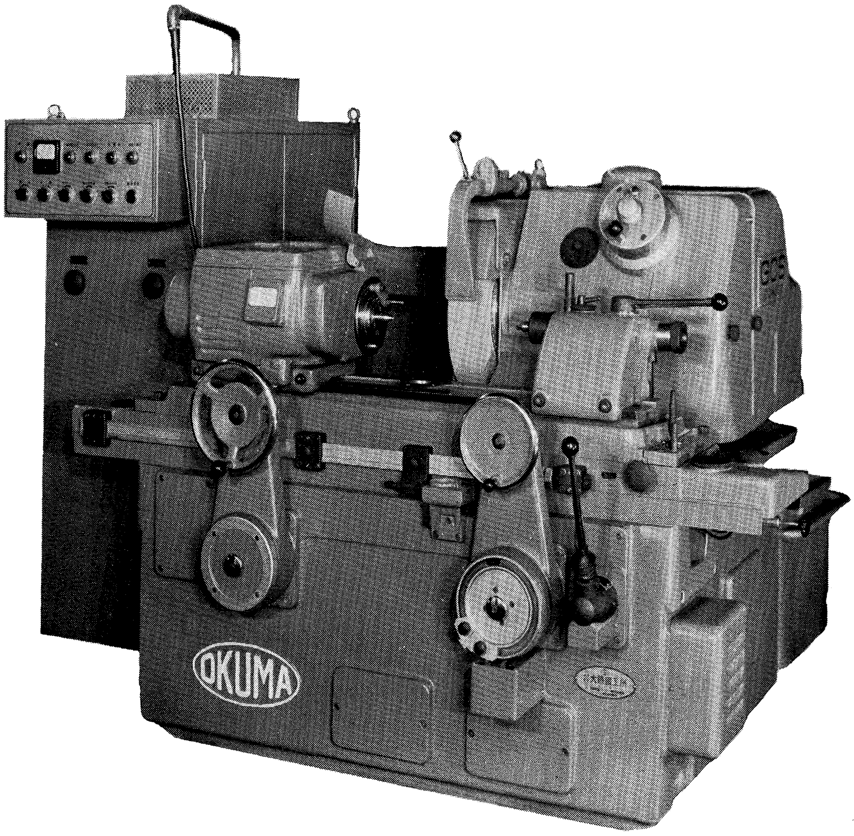

Fig. 10. Precision Grinder, Model GCS 100, by Okuma Machinery Works, Ltd.

supported with a patented, special plain bearing, and the bed of this grinder is of one piece to provide rigidity and stability. The control panel includes a work speed meter, a voltmeter, control switches, and pilot lamps to indicate the operating conditions.

The mechanical parts of the spark discharge machine shown in Fig. 11 include a movable head, a column, and a servomechanism. The movable head holds the electrode, and the servomechanism insures precise operation to limits of the order of several microns.

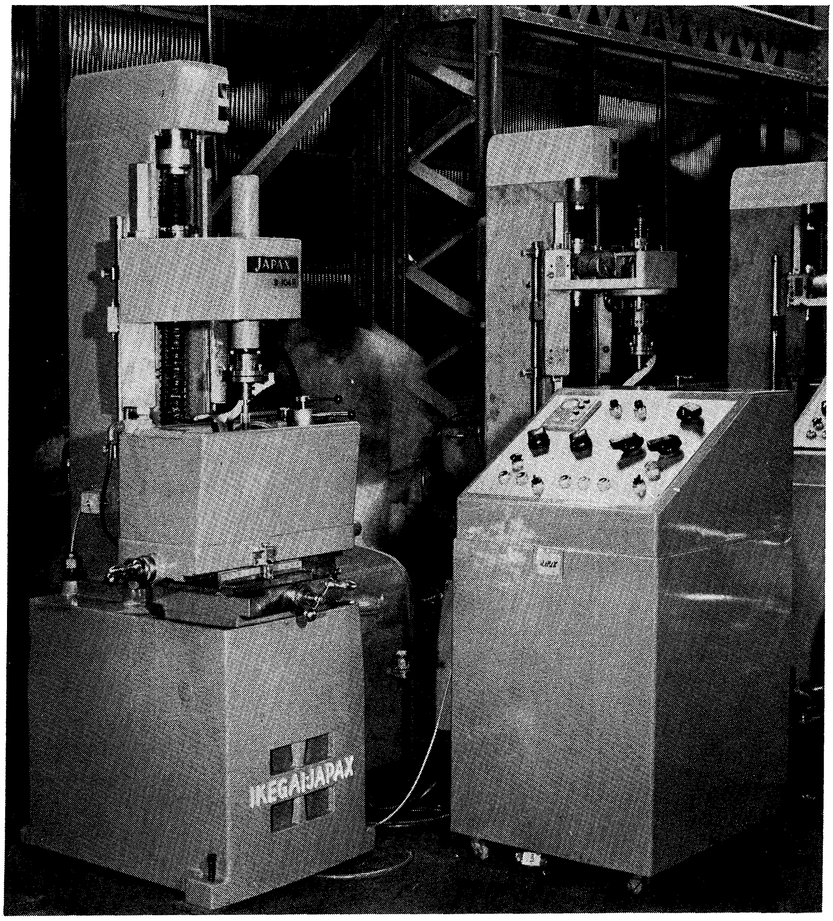

Fig. 11. Spark Discharge Machine, Japax D 104 H, by Japax, Inc.

The electrical parts consists of an impulse generator, an automatic servo-circuit, an adjusting and regulating apparatus, and safety devices. The impulse generator flashes impulse current for a period of several millionths of a second and repeats this discharge millions of times per minute. The sensitivity of the automatic servo-circuit permits it to respond within several thousandths of a second. The spark generating device can supply discharges at 50 to 1000 kc/sec for sustained periods.

The electric circuit system and the mechanical construction of this spark discharge machine were Japanese-developed and are protected by international patent rights.

The oscillator of the machine in Fig. 12 generates ultrasonic power of 1 KW at frequencies of 18 to 25 kc/sec. This power is transmitted to the vibrator which transforms electrical into mechanical oscillation through magneto-striction. This produces ultrasonic vibration of the necessary amplitude at the point of the tool by means of a conical horn. The vibrator is cooled with water. With this tool, precise machining operations can be carried out on any hard material.

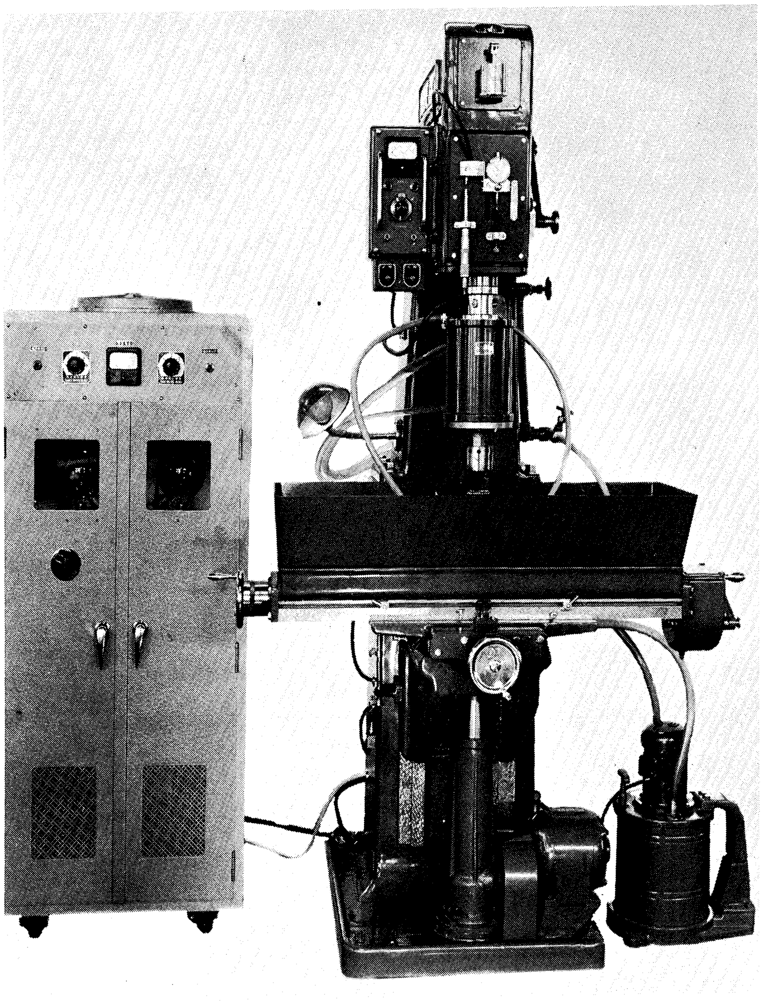

Fig. 12. Ultrasonic Machine, by Shimada Physical and Chemical Industrial Company, Ltd.

The transfer machine, shown in Fig. 13, performs all machining operations on the rear axle for compact cars, i.e.: boring, facing, drilling, and tapping of the middle part of the rear axle; boring, turning, facing, drilling, and chamfering of both ends of the rear axle; and washing of the product.

While there is little evidence in the U.S.A. of machine tools made in countries of the

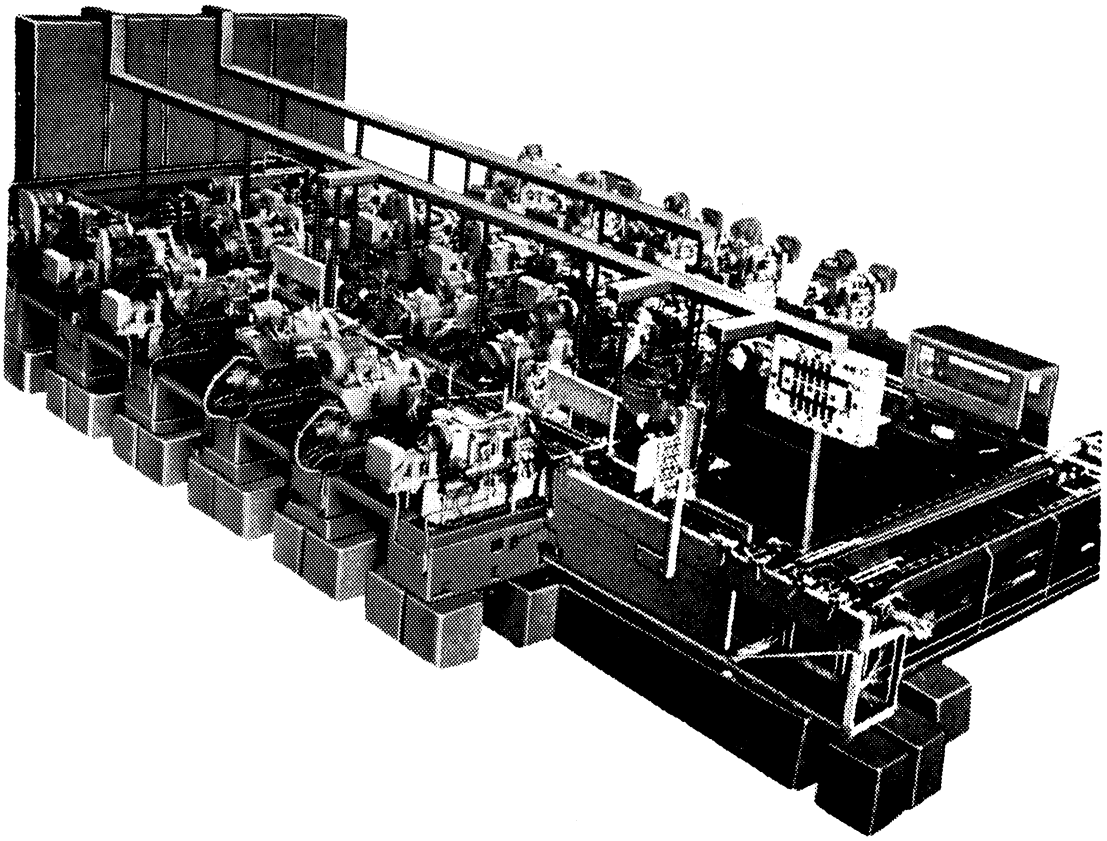

Fig. 13. Transfer Machine for Machining Automobile Parts, by Hitachi Seiki Company.

Soviet Bloc, they can be found working side by side with American-made machine tools in Latin America and Europe. The Soviet Union, their German Zone, and Czechoslovakia are the main producers.

In Fig. 14 is shown a horizontal spindle surface grinder with automatic cycle made by the Moscow Grinding Machine Works. A jig borer with an optical control system produced by the Swerdlowa Works in Leningrad is illustrated in Fig. 15. Another example of Russian machine tools is given in Fig. 16. This automatic relieving lathe is a product of the Kuibyshev Machine Tool Works. It can also be used for thread cutting and relieving of milling cutters.

A product of the Soviet Zone of Germany can be seen in Fig. 17. This is a Zerbst facing lathe with hydraulic copying equipment; the sequence of operations is controlled by punched cards. It should be remembered that the Soviet Zone of Germany did have a large share of the German machine tool industry before World War II.

Czechoslovakia was an industrial region of the old Austrian-Hungarian Empire, and during World War II the Germans transferred additional manufacturing facilities for machine tools and other capital equipment into the territory. The country is today one of the major

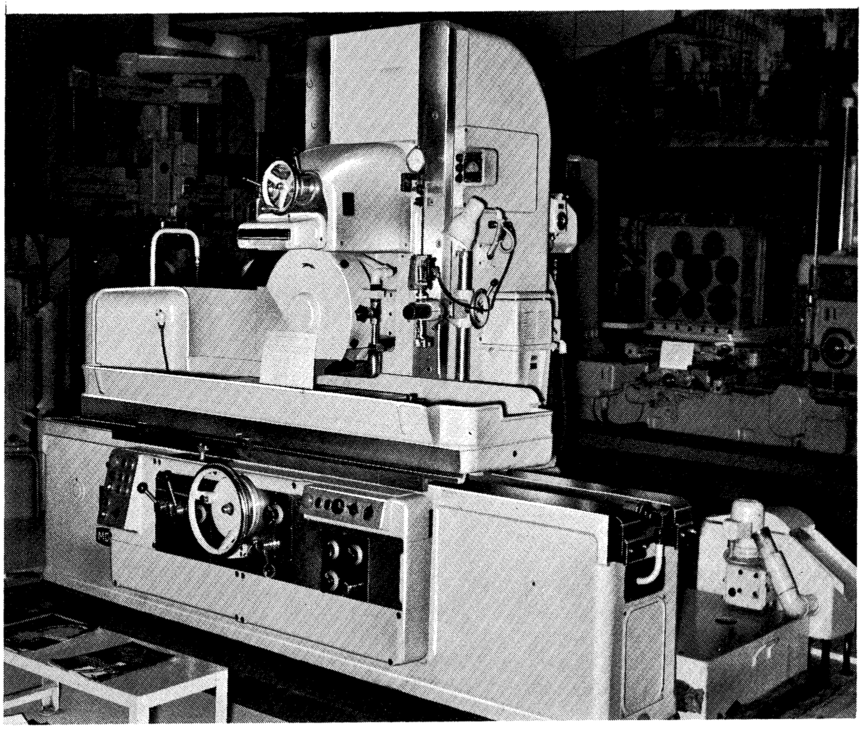

Fig. 14. Surface Grinder produced by Moscow Grinding Machine Works, Table size 15 x 75 inches.

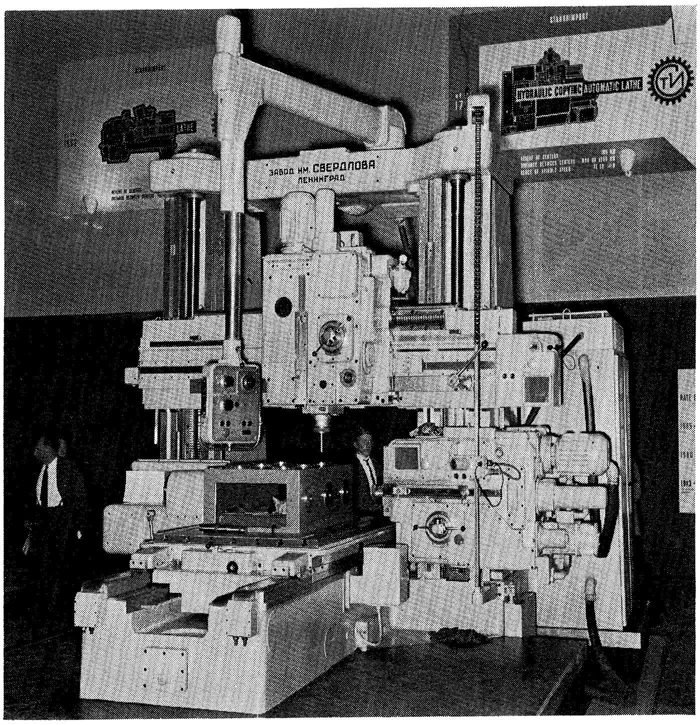

Fig. 15. Jig Borer, LP 97, made by the Swerdlowa Plant in Leningrad. Optical system and steel scales permit accuracy of 0.002 mm (0.000080 in.).

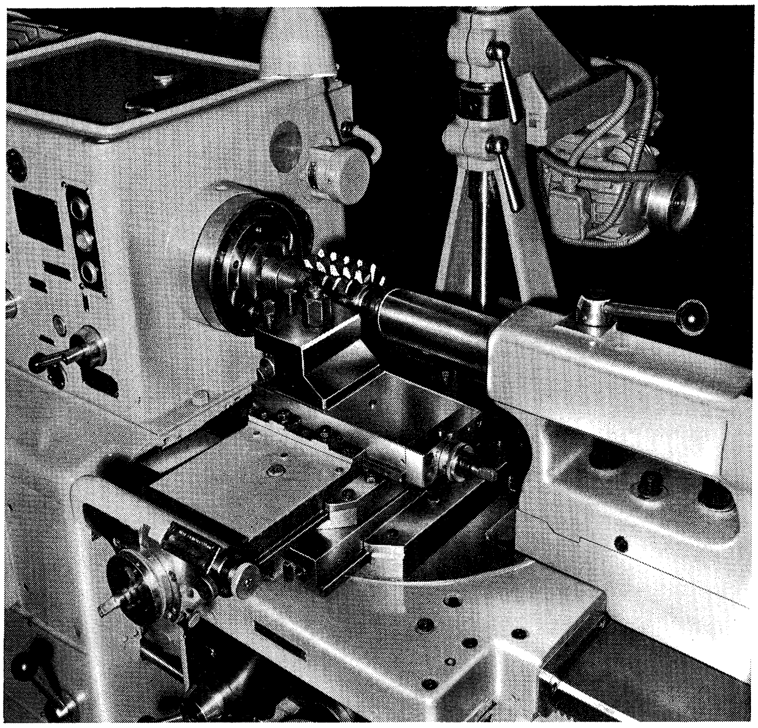

Fig. 16. Kuibyshev Automatic Relieving Lathe. Permits 9.5 in. workpiece diameter, 5 hp spindle drive; attachment on saddle slide is for grinding form relief.

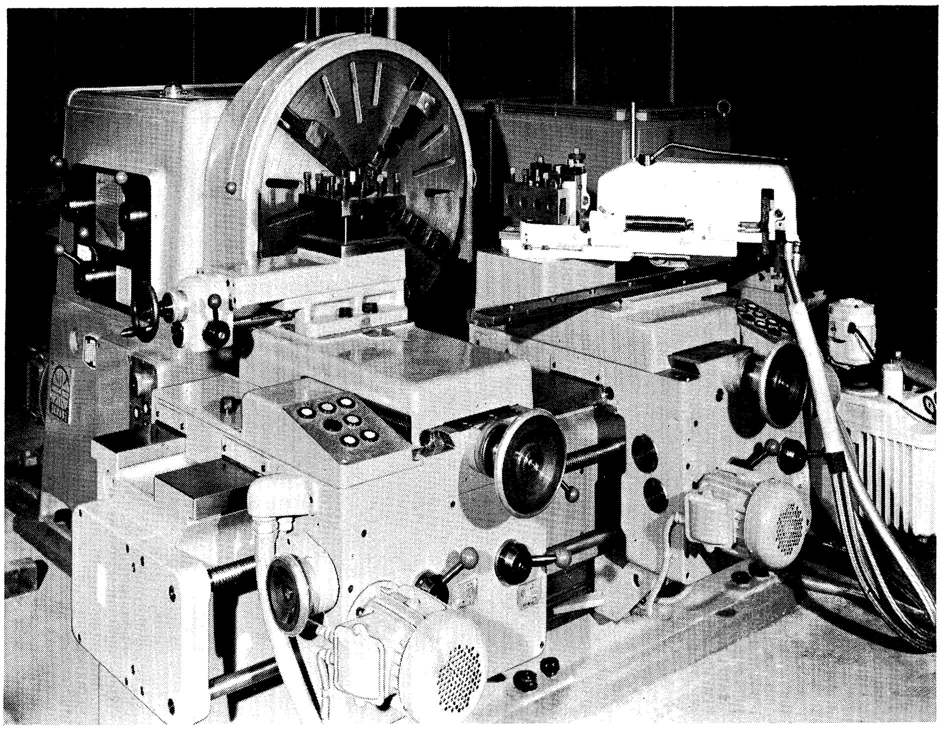

Fig. 17. German Facing Lathe. 25 hp stepless spindle drive. Swing 24 to 50 in., rapid traverse 90 ipm.

producers and exporters of machinery. A vertical milling machine made by TOS Kurim is presented in Fig. 18. The table movement is controlled in three directions by punched tape. Note the stiffening bars for the knee.

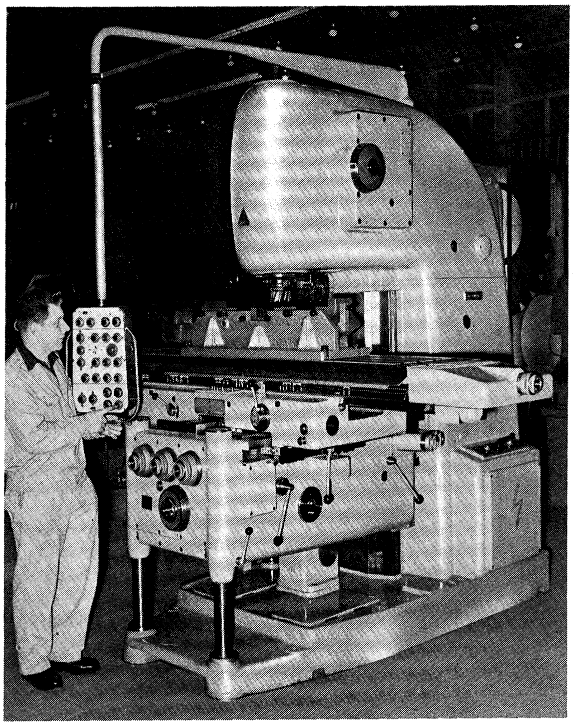

Fig. 18. 18 HP Vertical Milling Machine, FB 50V made in Czechoslovakia. 18 spindle speeds from 28 to 1400 RPM, 20 x 78 in. table size.

A turret lathe of Hungarian manufacture is shown in Fig. 19. The program controls for feed and speed were designed by the Hungarian Institute for Machine Tool Development in Budapest.

An example of Polish machine tool production is the copying milling machine in Fig. 20. This two-dimensional miller was produced in Warsaw and also has table stabilizers.

Chinese machine tools have been exhibited at various trade fairs of the Soviet Block countries. The jig borer in Fig. 21 is made in Kunming. It is similar to the German Lindner machine with its optical measuring equipment reading on stainless steel scales.

A series of articles dealing with machine tools from the communist countries as they were exhibited at the 1962 Leipzig Fair will soon appear in Machinery, London.

The following comments made by the production manager of a large Japanese machinery manufacturer may be of particular interest here:

> Speaking of the weak points of machine tools made in Japan, I think they are inferior to the top-class American machines in their cast parts--bed-casting,

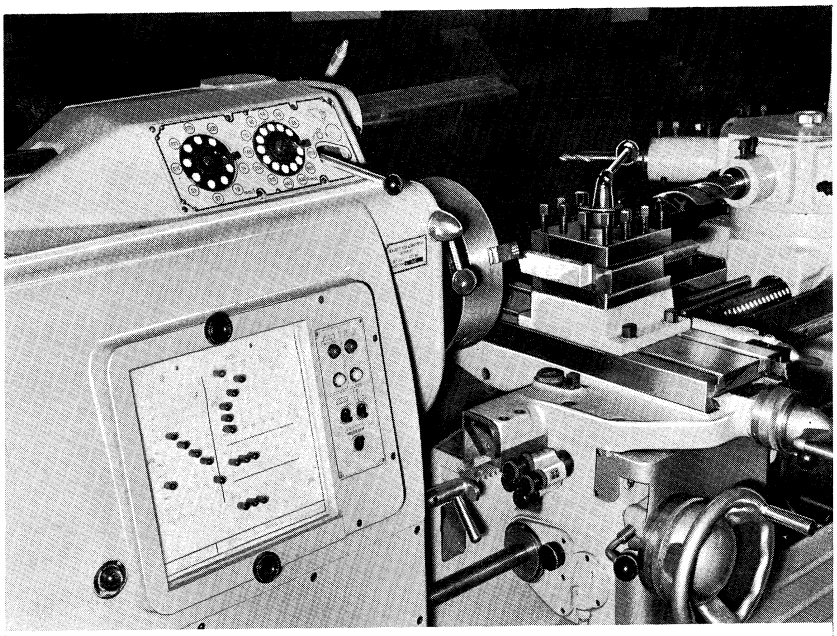

Fig. 19. Turret Lathe made in Hungary. Swing 21 in. over bed and 10 in. over cross slide.

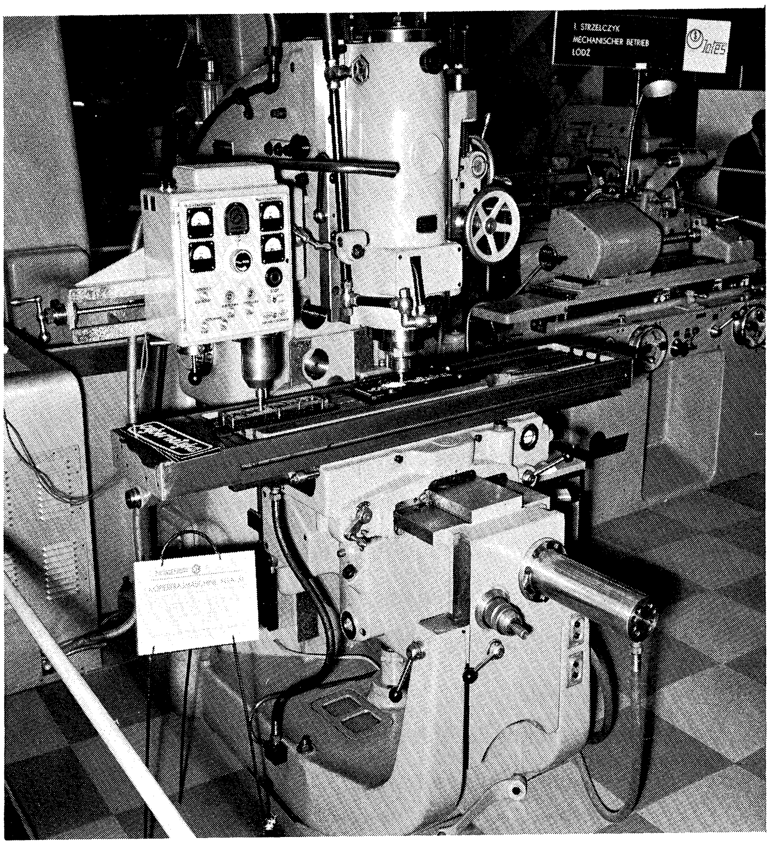

Fig. 20. FGA Milling Machine manufactured in Warsaw, Poland with electronic copying controls.

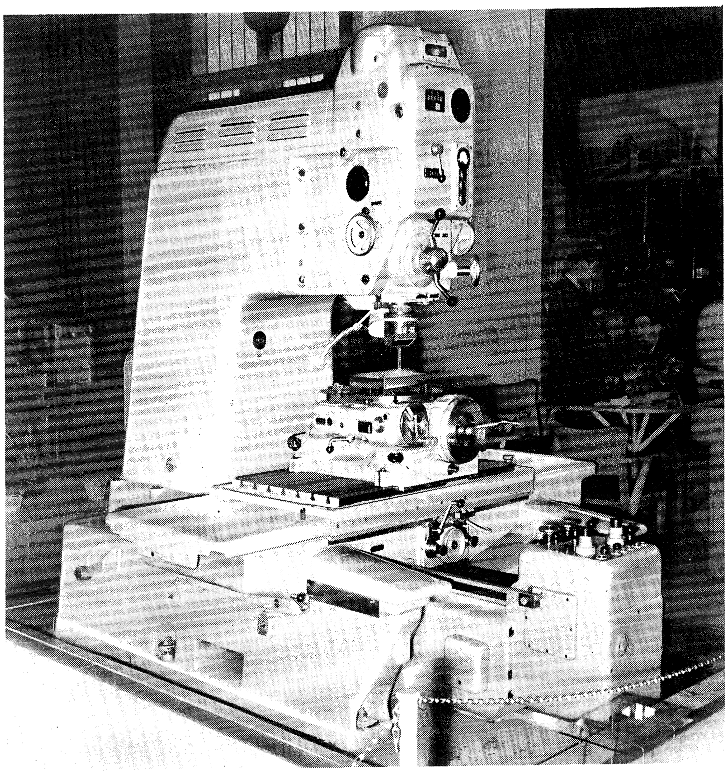

Fig. 21. T 463 Jig Borer made in China. Table size 43 x 24 in. Table moves on rollers over hardened steel strips.

spindle bearing, special plain bearing for heavy type precision grinder. Furthermore, as we have only a few good machine-tool parts-makers such as ball, roller and plain bearings, precision gears, pumps, electro and hydraulic units, our machine tools are more expensive than European and American products. Almost all kinds of machine tools are manufactured now in Japan, and their qualities are equal to the machines of the U.S., Switzerland, and Germany. However, it needs very long delivery since the manufacturing ability is narrowly limited. The following are machines of which I think European or American products are superior to Japanese in their qualities.

1) Practical Machine Tools:
   Accurate thread grinder, profile grinding machine, ultra-high speed (more than 80,000 - 100,000 r.p.m.) internal grinder, high-precision long bed surface grinder, die-sinking machine

2) Machine Tools for Production:
   Ultra-high speed lathe (more than 5,000 r.p.m.) precision gear grinder (we made Maag type or Pratt type grinders during the last war, but, sorry to say, they couldn't hold their accuracy for long time) heavy turning machine, hypoid gear generator, etc.

In Japan an optical system jig boring machine of the same quality as SIP is also produced economically, and is being exported to the Soviet Union. Equipment of the machine tool makers are rapidly expanded now in Japan. Imported machines from the U.S., Germany, and Switzerland are mostly precision planers, horizontal boring machines, and gear cutting machines. However, they are gradually displaced by home-made machines or remodeled. For example, at Toshiba Kikai Company, Ltd., gear cutting of the master worm wheels of the large type hobbing machine is done on their own 4-meter water worm wheel hobbing machine. Excellent turret lathes of Hitachi Seiki Company are being manufactured 200 units per month by line production. We imported the following machines this year from Europe and U.S. by reason of short delivery.

1) Jig Boring Machine	Burkhardt
2) Die-Sinker	Pratt & Whitney, Kellers, Cincinnati Milling, Hydrotel
3) Milling Machine	Induma, Italy

SUMMARY

Although there exist today no international standards for machine-tool structures or for checking the performance of machine tools, there is a widespread acceptance of various makes of machine tools throughout the world. It speaks well for the high level of machine tool engineering that it is possible to make all the precision equipment to implement the increase in productivity of industrial nations and those countries that are now beginning to industrialize. With the demand for more quality products the requirements for machine tools will become more stringent.

There is major activity in numerical control, with the emphasis upon reliability and economy. Extreme precision requirements in which small temperature variations already produce unacceptable parts will spur the demand for machine tools to new heights in regard to design and will intensify the engineering requirements of machine tool production.

ACKNOWLEDGEMENT

Professors Okushima and Hitomi of the Department of Precision Engineering, Kyoto University, Kyoto, Japan were most cooperative in writing the section on Japanese machine tools. Mr. Masanori Tani, Manager of Engineering Production, Nittoku Metal Industry Company, Ltd., Tokyo, supplied catalogues and performance data on Japanese industries in a very helpful way.

Dean A. B. Drought of Marquette University permitted me to quote from his paper presented to the Space Age Tooling Seminar at the University of Arizona. Machinery Publishing Company, Ltd., London N.W. 1, England furnished the illustrations for the machine tools from communist countries. My special thanks to all of them.

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3

THE FUTURE OF THE MACHINE-TOOL INDUSTRY IN MICHIGAN

Orlan W. Boston

The machine-tool industry is basic, that is, its product is more permanent than the common consumers' goods. Machine tools create themselves and all other manufactured items and so deserve constant review and improvement.

Every company should make a critical estimate of itself at frequent intervals. This analysis should cover its services, products, and personnel, to see that the services are adequate, and, if possible, better than those of competitors; that the latest techniques and materials are embodied in the product design; and that the personnel is of the best. Only by keeping up-dated can a company meet the future with confidence.

Service to Customer

Assuming a company has a well-developed product, we might ask what services to its clientele should be offered. Information which affects the operation of the product should be available to the customer along the following lines:

1. The type of cutting tool material and tool shape best suited to specific conditions.
2. The best combination of speed, feed, and depth of cut for each given type of work and tool.
3. The power required to remove each of the many metals under various conditions.
4. Procedures to obtain the best surface finish.
5. The type and application of cutting fluids for each process and material, that is, whether to cut dry, use an emulsion, a forced mist, etc.

Optimum Design Features

Again, concerning your own product, we might raise some questions regarding features of design.

1. Are you using materials best suited for specific design of each part, consdering its service, cost, and particular quantity of production? For example, frames and structures may be made of castings, of gray iron, Mehanite, ductile iron, pearlitic iron and steel, or of welded steel shapes. Small parts may be made of malleable iron castings, zinc die castings, a sintered powdered bronze, plastics, steel forgings, aluminum stampings, or brass extrusions.
2. Are your designs based on American Standards wherever possible?
3. Are designs adequate for interchangeability of parts and unit construction for ready service and repair?

4. Are your designs aimed at minimum deflection of parts, low wind-up in power transmission, and mimumum vibration of base, work, and tool?
5. Does your power source limit the capacity of your machines?
6. Are machine controls convenient and adequate for the safety of the operator and the efficient operation of the machine?
7. Do your machine drives provide a wide range of infinitely variable speed?
8. Are your machines adequately equipped to apply cutting fluids, and remove the chips from the cutting zone?
9. Are they pleasing in appearance?

The machining panel of the Committee on Development of Manufacturing Processes of the Aircraft and Astronautics Industry has listed three major problem areas for future development by the metal removal industries: increased ability to machine high-strength, heat-resisting materials; increased versatility to produce small quantities of complex parts of a great diversity of materials; and closer tolerances on machined parts.

Diversification

Large companies constantly carry on studies of marketing, research and development, as well as other investigations for additional items to produce, in order to insure a uniform sales and manufacturing program from season to season and from one economic cycle to the next. That the machine tool industry is cyclic is well known. Diversification is therefore a promising means for protecting stability and growth.

When new materials to provide high strength and withstand high temperatures are involved, it is almost impossible to machine them by conventional methods. New systems of non-chip-forming methods are being developed to bring the parts to final shape, size and finish. A number of these alternate processes are now being used, particularly in the missile and aircraft industries.

The following examples illustrate how an industry might expand into new fields with diversification as one objective by adding to its line one or more of the following non-chip-machining methods:

1. Electrical discharge machining, used to disintegrate metals by means of high frequency controlled sparks, chiefly for forming cavities.
2. Electrolytic grinding, in which an electro-chemical de-plating process is used on conductive materials.
3. Ultra-sonic machining, involving the removal of hard, brittle materials by bombarding them with small abrasive particles carried in a liquid flowing between a rapidly oscillating punch and the work.
4. Electrolytic machining and sawing, employing an electrolyte which dissolves the reaction product formed on the work piece by an electro-chemical action between the electrode and the work.

5. Chemical milling for shaping metal parts to shallow depths and complex contours by controlled chemical dissolution when submerged in a suitable reagent, to accomplish the same results as end milling on large thin surfaces.
6. Electron beam melting and welding, carried on in a vacuum chamber, focussing beams of electrons on the work by magnetic and electrostatic lenses, with limited application for drilling and slotting.
7. Plasma jet or torch, producing extremely high temperatures with an electric arc operating in the open, producing "plasma," a term used to denote the state of matter as a neutral collection of electrons and positive ions. This is still in the development stage. (See American Scientist, March 1962, p. 59.)
8. Abrasive jet of high velocity streams of gas or liquid, in which the fluid may carry an abrasive, for parting or trimming sheets.
9. The optical laser machining system, using light; this is one of the most recently developed methods for micro-machining and welding; it is the subject of research and development by one of our local laboratories. (See U.S. News and World Report, April 1962, p. 47.)
10. Shock waves, formed by an electric spark within a liquid producing a very high force available in all directions.
11. Machining at high temperatures by conventional methods those metals difficult or almost impossible to machine at normal temperatures.
12. Explosive or high-energy forming and forging, often very satisfactory and economical.

Other items of inquiry, analyses, and processes to improve the status quo could be presented—but let the above suffice. The Division of Engineering and Industrial Research of the National Academy of Sciences has listed many problems of this nature.

Education

During the coming years manufacturing will require engineers with training quite different from that of the past and present. New materials, new tools, new processes, more programmed numerical control, and so forth, will be the order of the day. To keep prices of manufactured goods competitive with other American and foreign companies, those taking advantage of this new technology will be in the driver's seat. Where are these engineers coming from and what is their capacity? Many students in high school and college become interested in production and manufacturing, once they learn about the opportunities available after graduation. They can't all arrive at success by coming in the back door like the poor student who dropped out of high school and wasn't heard from until he attended a reunion some twenty years later. His school mates were discussing him as the most likely to have failed, but he turned up in a car so long it had to have a joint in it to turn corners. When asked the secret of his success he said he had run across a product that could be made for a dollar and sold for five dollars and commented that "that four per cent mounted up mighty fast."

The current objective of engineering education, accepted largely by the teaching profession, is that students be prepared comprehensively, with emphasis on mathematics and the basic sciences in order to develop new systems, new processes, and stimulate imagination in manufacturing. Most large companies now provide one, two, or more years of in-plant training for the newly employed graduate so he may work in and observe several departments. In this way the employee is not expected to become an expert in a specialized field, but can become familiar with the various aspects of the manufacturing activities. This experience gives him a good idea of the type of work for which he is best suited and in which he is most interested. Some large companies have found the cooperative system to their advantage. The student works in industry and studies at college in alternate periods.

Small plants, on the other hand, hope to employ graduates who can be of immediate assistance in applying their training. The advantage in this is that the employe can observe most of the functions of the business directly and offer assistance where he feels qualified to do so. In this way, he works more closely with the administrative officers than in a large concern.

Many industries work with schools at all levels to impress on those responsible for the curricula the need for engineers trained to enter manufacture. The request for employment of such students is one effective method of keeping the courses in line with the needs of the manufacturer. Conferences between representatives of industry and the colleges can be most helpful. The support of research, scholarships, opportunities for plant visits all promote interest in current problems and their solution. More effort is needed on the part of professional engineering societies, universities, industry, and government to guide qualified students into engineering curricula. During the past decade, engineering enrollment has fallen off dangerously.

Nuclear power and electronics call for a new type of engineering science. Men being trained in these fields are in great demand, due primarily to the tremendous output of military requirements, and the development of computers and numerically controlled equipment. A high degree of automation will keep manpower requirements at minimum levels to keep costs on a competitive basis. This requires a large investment in specialized equipment which can be justified by mass production. The design of the product must be fixed for a considerable amount of time to make such a set-up economically sound. Many highly automated machines are so tooled that they can be altered to run to advantage on a limited number of similar parts. Smaller companies producing a variety of parts are most flexible in their operation and can introduce new or non-standard items at reasonable cost. Computer-control technology has greatly extended automation and will expand rapidly in the near future. Numerical control will keep machines operating at higher rates of speed and with closer tolerances. It is applicable to mass production machines as well as those used in low production where versatility is needed, as in the air-space industries. Even in the field of inspection this has been proved to be invaluable.

Summary

To sum up the points I have tried to make to encourage us in the face of these changing times, let me repeat:

1. A variety of services should be developed and made available to users of your products.
2. You should analyze critically all features of design and construction to make sure all weaknesses are eliminated.
3. You should consider new processes and products to diversify and stabilize to avoid cycles of high and low markets; similarly liquidate non-profit activities.
4. You should employ graduate engineers with scientific training who have had courses dealing with manufacturing processes.
5. You should take an interest in schools of lower levels as well as college to inform the staff and students of your problems.
6. You should permit plant trips and demonstrations to awaken the interest of students in manufacturing.
7. You should engage some of the college staff in research to work closely with your own staff, at the school or within your own plant.
8. You should encourage your engineers to work closely with engineering societies, attend meetings, seminars and exhibits and serve on committees, in order to keep up with recent developments in other industries and plan for the future.

Section II

UNIVERSITY RESEARCH IN MACHINE TOOLS AND MACHINABILITY

4

UNIVERSITY RESEARCH IN MACHINE TOOLS AND MACHINABILITY

Lester V. Colwell

My objective on this occasion is to present and discuss a few highlights of research in metal processing as it has been carried out over the years here at the University of Michigan. The material to be presented is necessarily technical in nature and represents a wide variety of topics. Therefore, each topic will be discussed only briefly and somewhat superficially in order to emphasize the scope of the work.

History of Research in Metal Processing

It will be worthwhile to review briefly the history of manufacturing research in order to place the activity here at the University in its proper perspective in relation to metal processing research elsewhere. The first substantial effort to carry out research in metal cutting and to apply it to the manufacturing effort was made under the direction of Frederick W. Taylor of the Bethlehem Steel Company at the beginning of the twentieth century. His results were presented in an historic paper entitled "The Art of Cutting Metals" before the American Society of Mechanical Engineers. This work signals the beginning of scientific manufacture in the United States, and it is now appropriately recognized at the Smithsonian Institution in Washington.

Professor Wallichs studied Taylor's work and introduced it first to Germany and then to the rest of Western Europe soon after. He also organized one of the first metal-cutting research laboratories in Europe at the Technische Hochschule, Aachen, Germany. During World War II and after, similar laboratories were organized, and substantial research in metal-cutting and other metal-processing operations has been carried out all over Europe, including England, as well as in Japan. The scope, depth, and magnitude of such activities are particularly notable in Russia, Germany, Japan, Czechoslovakia, Holland, England, and Italy. More recent starts of a significant nature have occurred in countries like Yugoslavia.

Taylor's work was followed in the United States by the setting up of laboratories at the Cincinnati Milling and Grinding Machine Company, where Hans Ernst developed the well-known research program now under the capable direction of Dr. M. E. Merchant. Similar research, but on a smaller scale, has been carried out by Dr. A. O. Schmidt at the Kearney and Trecker Corporation in Milwaukee, Dr. Hahn at the Heald Division in

Worcester, Dr. Tarasov at the Norton Company in Worcester, Mr. Leif Fersing at the Jones and Lamson Company in Springfield, Vermont, and by Mr. Albrecht at the Monarch Machine Tool Company in Sidney, Ohio.

Professor O. W. Boston started research in metal processing at the University of Michigan just after World War I, and it has continued here at an ever-expanding rate since that time. Work has also been going on at the University of Illinois for about the same period of time. For some years these were the only universities in the United States engaged in research in metal processing and in teaching the application of science and engineering to manufacturing processes. Substantial programs later were developed at MIT under the direction of Professor M. C. Shaw and at the University of California in Berkeley under the direction of Professor E. G. Thomsen. Last September, Professor Shaw became head of Mechanical Engineering at the Carnegie Institute of Technology, where he is organizing another substantial research program. Student research activities in metal cutting are also under development at Pennsylvania State University, Syracuse University, Ohio State University and the University of Texas.

Metal-Processing Research at the University of Michigan

Others who have preceded me on this program have told you about the integration of research and teaching here at the University. The research in metal processing is similarly integrated. This gives rise to several forms of research activity. One form is the academic research carried out by individual faculty members on their own time. The problems undertaken in this activity may have some obvious application, but in many cases they consist of probing and analysis for the fundamental causes of various phenomena. Much of this work is carried on without any special financial support, although occasionally grants from foundations or research funds of the graduate school are made available.

Another form of research activity is carried on by students as part of their instructional program. In the earlier stages, undergraduates carry out simple investigations as part of formal courses wherein laboratory work constitutes only a part of the total instruction given in the course. Later on, both undergraduate and graduate students can elect to carry out more extensive studies as individual projects under faculty supervision. Much of this activity leads to publication in the technical journals, and occasionally to a doctoral dissertation.

A substantial fraction of the metal-processing research here at the University is carried out under contract with industrial sponsors. Occasionally there is also some support from a department of the Federal Government. This work is carried out by both undergraduate and graduate students working on a part-time basis and also by full-time personnel who are graduate engineers. All of this work is under the technical supervision of staff members of the Mechanical Engineering Department.

Details of Research Programs

The following figures will illustrate only a few of the wide number of subjects studied in manufacturing research here at the University over the years. They are divided into five groups. The first group illustrates some of the equipment and instrumentation developed here for research purposes, while the remaining four groups illustrate sample results and features of either specific programs or study areas.

Equipment and Instrumentation

Others before me on the program have referred to various research activities which have led to the development of new products manufactured by new companies often set up by people from the University. These have been referred to as "spin-offs." Figure 1

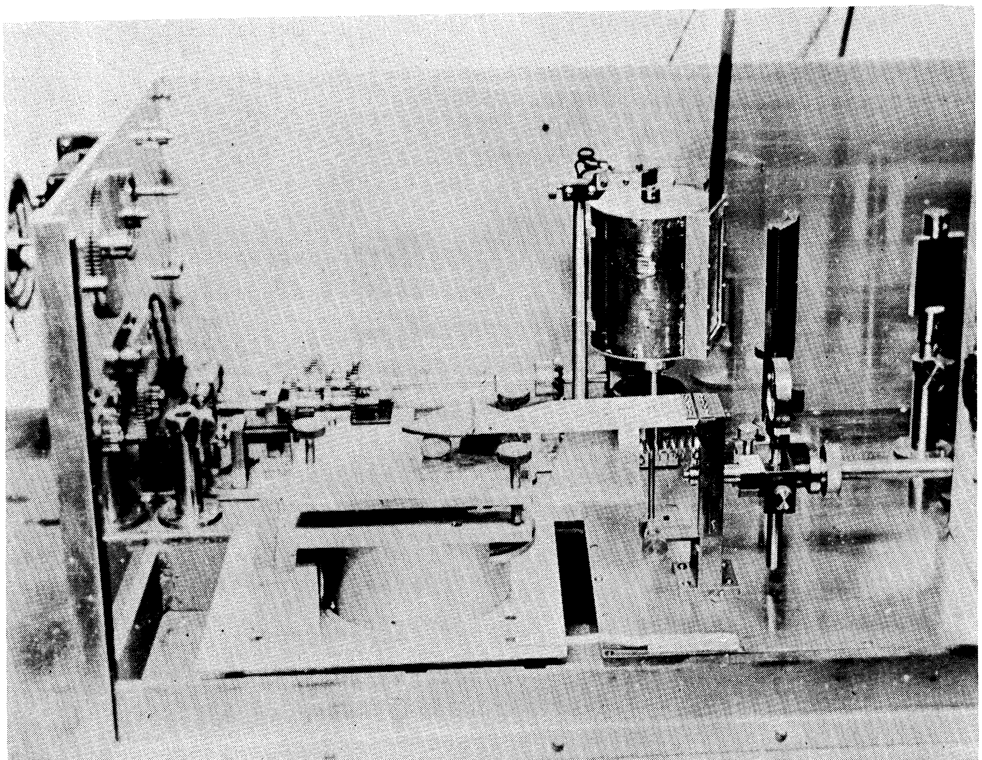


Fig. 1. The Profilograph. A surface roughness measuring instrument which reproduced the profile of a surface by recording the deflection of a light beam reflected from a small mirror rotated by a sharp diamond as it traversed the surface to be inspected. This original development is the ancestor of the current Profilometer, which is in common use in industry for measuring the roughness of machined or ground surfaces.

illustrates one such development of this type. It is known as a Profilograph. It is an instrument which determines the profile of a surface by tracing a sharp diamond over the surface. In this particular instrument, the motion of the diamond rotated a small mirror which in turn deflected an incident beam of light, thus producing an amplified trace of the profile on a rotating photographic drum contained in the cylinder which can be seen just right of center in the back of the apparatus. A system of mirrors and prisms produced profiles amplified by 2000 to 5000 times.

The Profilograph was developed by Dr. E. J. Abbott and Professor Floyd A. Firestone in the Physics Department of the University back in the early 1930's. Dr. Abbott left the University to form the Physicists Research Company and to manufacture the well-known Profilometer, which is an industrial application of the original Profilograph. The Profilometer is now manufactured by the Micrometrical Division of the Bendix Corporation here in Ann Arbor. The original Profilograph shown in Figure 1 is now being prepared as an exhibit for the Smithsonian Institution in Washington, D.C.

Figure 2 illustrates a laboratory set-up for studying the influence of spindle flywheels

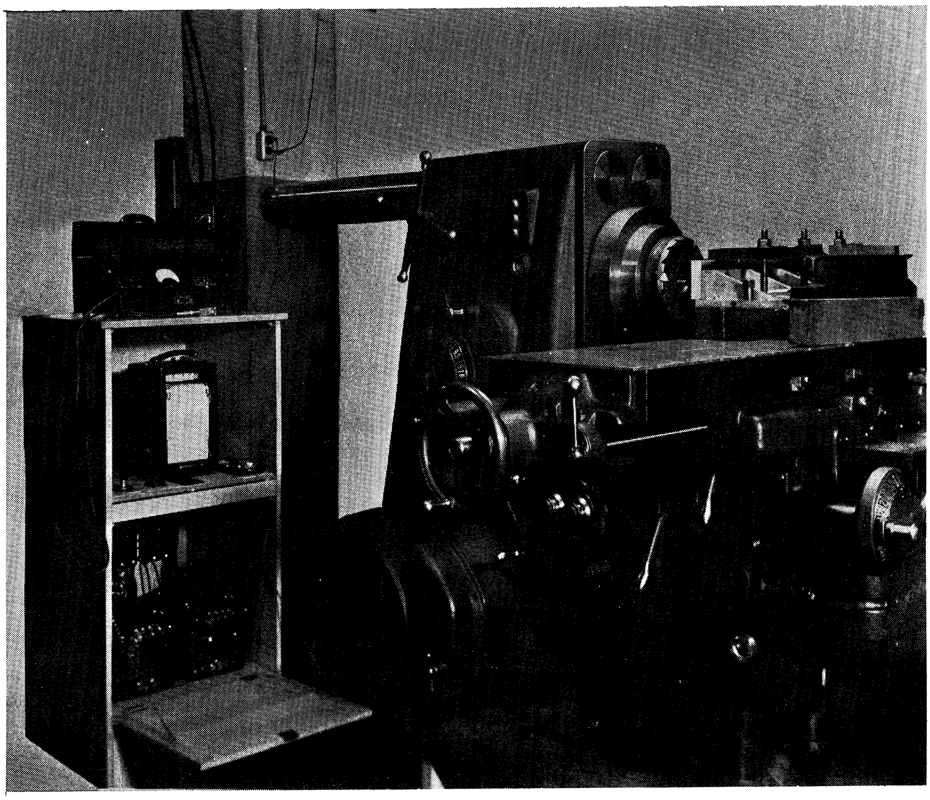


Fig. 2. Illustrates a laboratory set-up for studying the effects of flywheels on a milling operation. The flywheel is mounted directly on the end of the milling machine spindle, and a single-toothed face milling cutter is mounted directly upon the flywheel. Additional steel rings made it possible to double and quadruple the inertia of the flywheel shown.

on metal cutting in a milling machine. This investigation was carried out during World War II as part of a broader program devoted to increasing the productivity of existing machine tools. Power requirements, surface finish, and nature and rate of tool wear were observed while milling several work materials over a broad range of cutting conditions.

Two significant results developed from this study. One was that no improvement could be obtained by the use of flywheels on this particular machine because it was new at that time and represented a relatively modern design which was virtually rigid. On the other hand, the application of similar flywheels to an older machine of World War I vintage did increase tool life and improve performance substantially because the flywheels provided added stability to the older and relatively less rigid machine.

The second development concerned the role of damping in metal cutting operations. It was found that pre-dulling of the cutting tools through slight rounding of the cutting edge produced sufficient damping in the cutting zone to reduce the effects of impact resulting from vibrations in older, less rigid machines. This resulted in a substantial improvement

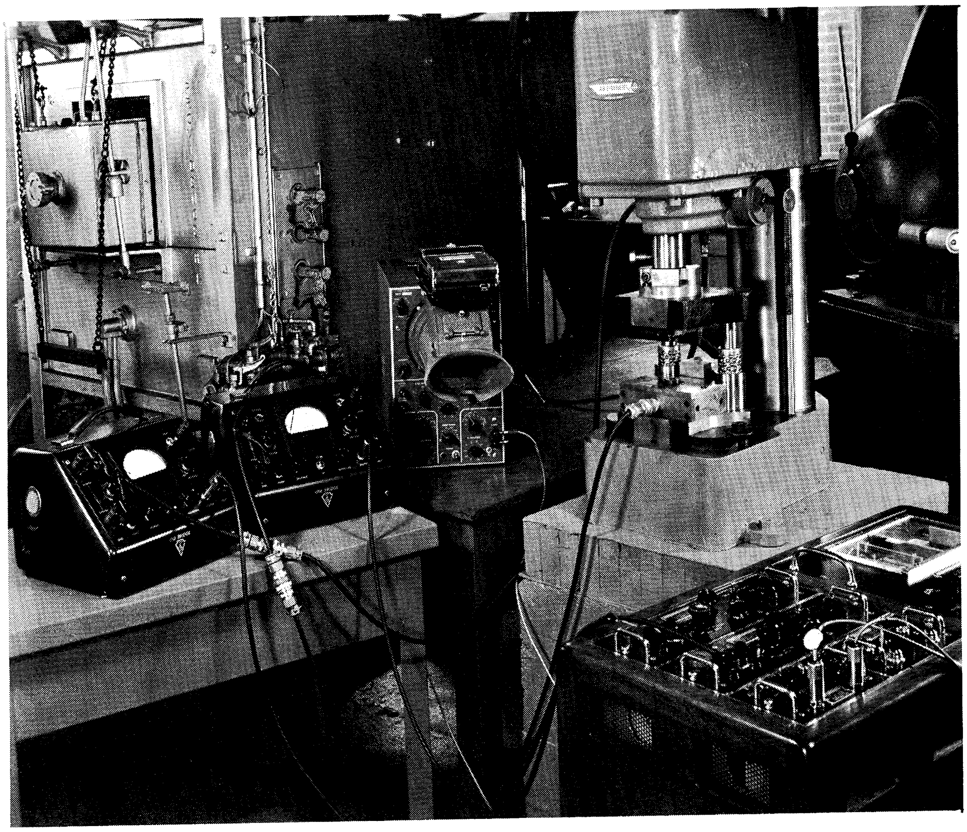


Fig. 3. A laboratory forging die set-up in an air-impact hammer for the study of lubricants applied to the ends of a test specimen. Carrier-amplifiers and an oscilloscope provide records of the forces and motions during the operation.

in both tool life and surface finish. On the other hand, the same pre-dulling resulted in decreased tool life in more rigid machines wherein chatter vibrations were less frequent.

Figure 3 shows the instrumentation and a laboratory forging die set-up for studying lubrication in impact forging. Resistance-wire, strain gages were incorporated in the forging die to provide continuous records of force and die motion. This made it possible to study the behavior of lubricants at the high velocities peculiar to commercial operating conditions. This study developed new information on the behavior of lubricants and led to the development of better lubricants for this type of operation.

Figure 4 shows a drawing die set-up in a hydraulic press. The use of resistance-wire, strain gages made it possible to control and record the punch motion and the hold-down pressure, and to record the drawing force and the radial pressure in the die. This set-up also was used to study lubrication in a plastic working operation. It also led to the development of new and better lubricants for operations on sheet metal.

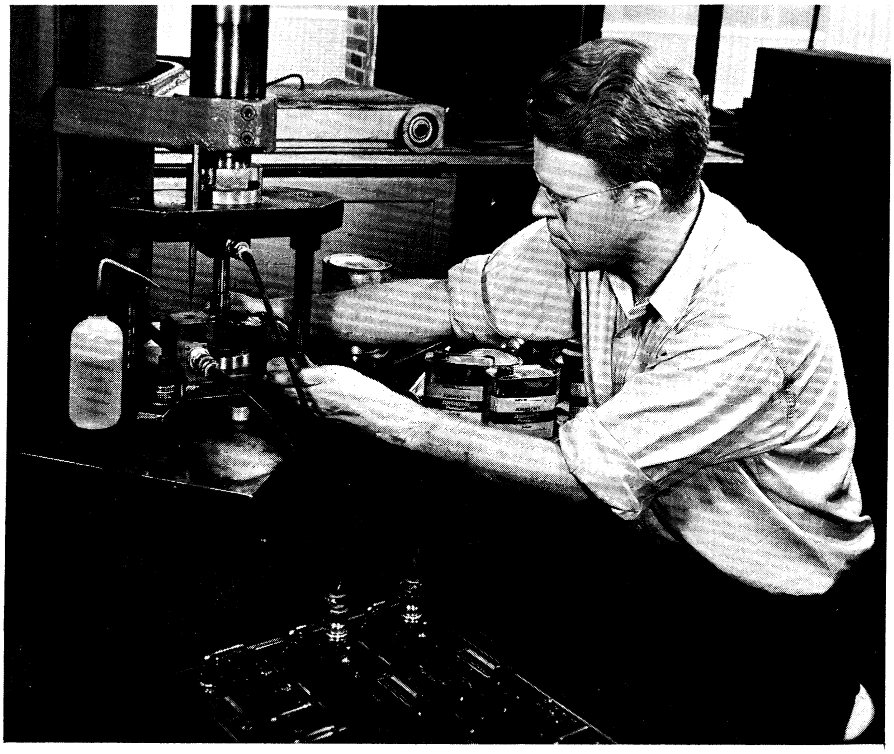


Fig. 4. A laboratory drawing die set-up in a hydraulic press, for drawing sheet metal cups. Electrical instruments provide continuous records of punch motion and velocity, drawing force, blank hold-down pressure and radial force on the draw die.

Figure 5 shows a special machine tool consisting of a combination high-speed lathe and milling machine. It is located in the Alcoa Machinability Laboratory here at the

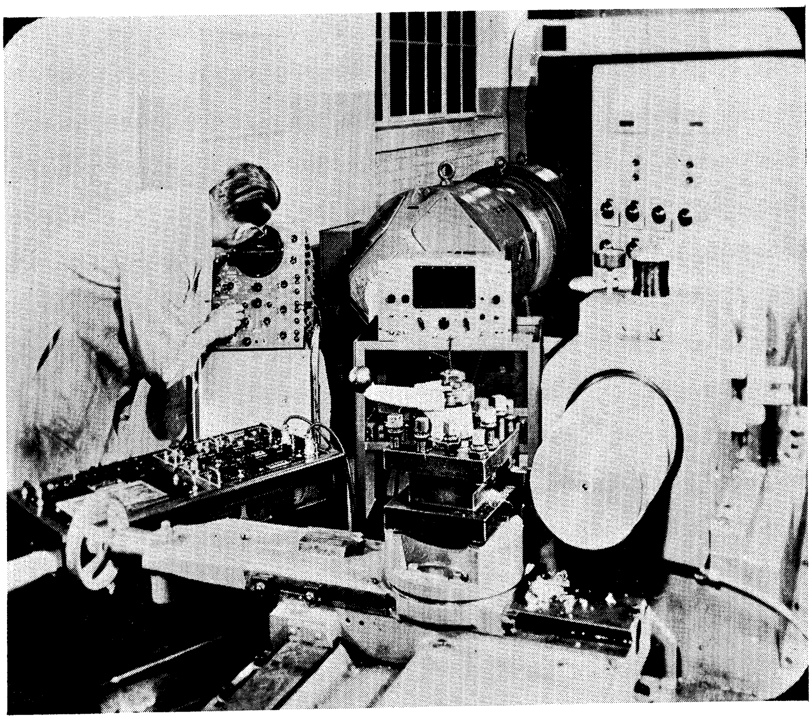


Fig. 5. The high-speed lathe located in the Alcoa Machinability Laboratory of the University of Michigan. The 14-inch swing lathe is shown turning an 8-inch diameter aluminum shaft at 10,000 rpm, or at a cutting speed of approximately 20,000 feet per minute.

University. The machine was developed during World War II through the joint efforts of the Aluminum Company of America, the Reliance Electric Company and the Cincinnati Milling and Grinding Machine Company. Later it was given to the University of Michigan by the Aluminum Company of America for research in high-speed machining.

The machine is equipped with a 300-horsepower, variable-speed drive, making it possible to rotate the spindle at any speed from 0 to nearly 10,000 revolutions per minute. It has been used to provide cutting speeds up to 40,000 feet per minute in turning operations, and for milling speeds up to about 20,000 feet per minute. It has been demonstrated both here and elsewhere that metal can be cut at speeds ranging from 3 to 5 times as high as the speeds normally used in industry for grinding.

This machine has provided the opportunity to develop new instrumentation for the study of cutting forces, vibrations, and temperatures at these very high speeds. For example, in a milling cut an individual tooth may cut for a period of only 25 to 50 millionths of a second, during which time it is now possible to measure the forces, temperatures, and vibrations which occur during such a cut. Research at these high speeds is providing new information on the nature of metal cutting and thereby strengthening the technological background upon which industrial manufacturing operations can be designed.

Titanium Research Program

One of the larger programs of contract research undertaken by the University in the manufacturing area was devoted to a study of the machining characteristics of titanium for the Federal Government. The Massachusetts Institute of Technology undertook the research investigations in grinding of titanium, and the University of Michigan carried out studies on thick-chip machining operations. Titanium is one of the new materials of construction which attracted great interest back in the early 1950's. More research on the metal-processing characteristics of titanium has been carried out than for perhaps any other metal. It is regrettable that similar programs have not been carried out for materials like steel, cast iron, aluminum and other non-ferrous metals which are used in far greater tonnage than titanium.

Figures 6 through 9 inclusive show typical information obtained on this particular program. Figure 6 shows metallographic pictures of chips in the process of formation from three significantly different metals. The specimens were obtained by making cuts in a shaper wherein the maximum forward travel of the tool was not sufficient to completely

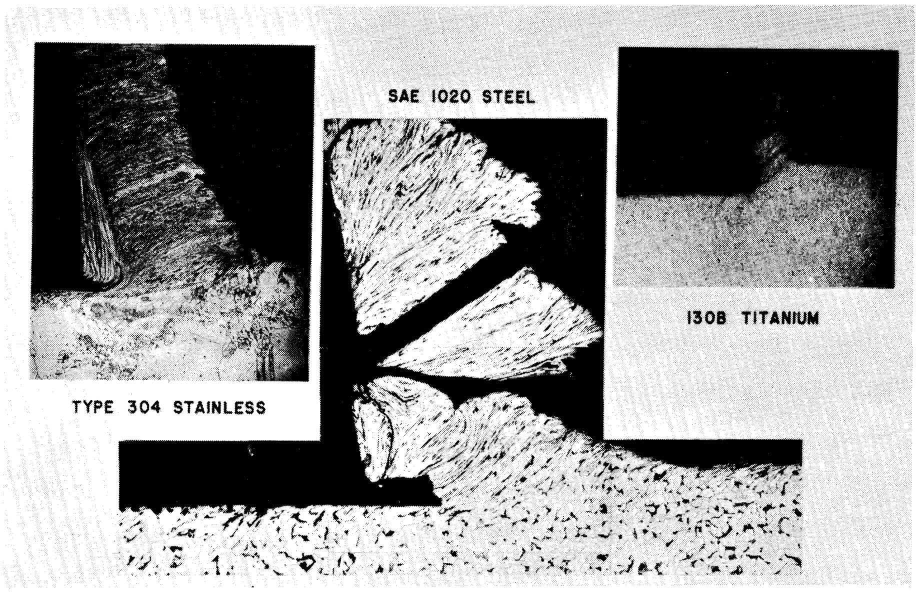


Fig. 6. Chip formation versus material cut. Cutting conditions: at end of shaper stroke with 9" stroke, 9 strokes per minute, 0.005" depth of cut, 0.250" width of cut. Tool signature: 8,0,6,3,0,0,0. Magnification 50x. S.A.E. 1020 steel, nital etch; Type 304 stainless steel, electrolytic chromic acid etch; Type 130 B titanium; 48% hydrofluoric acid in glycerine etch.

remove all of the material so that the chip remained on the workpiece. In all three instances the cutting conditions were identical with reference to the size of cut.

From right to left in the figure, the three different work materials are stainless steel, low carbon steel, and a titanium alloy, respectively. The stainless steel shown at the upper left produces a continuous chip with a built-up edge or tool loading between the underside of the chip and the cutting tool, which was located to the left of the chip.

Essentially the same behavior is evident in the cutting of the low carbon steel as shown at the center of the figure, except that the chip is very much thicker and appears to be broken, although it is actually a continuous chip that was severely segmented, thus appearing to be disconnected in the illustration. As in the case of the cutting of the stainless steel and the titanium, the cutting tool was located at the left of the chip, indicating that a crack preceded the cutting edge. This can occur as the illustration demonstrates, but this is but one phase in a pulsating process wherein the chip stops or refuses to slide along the cutting tool, thus shearing ahead of the work surface. The fact that we were able to obtain this particular condition is something of a fortuitous accident, since that portion of the chip in contact with the workpiece at the lower level is in the act of buckling just prior to the renewal of motion of the chip along the cutting tool.

The chip formation for the titanium alloy illustrated at the upper right in Figure 6 demonstrates two points of significance. The first is that the very thin chip relative to those produced by the stainless steel and low carbon steel gives rise to a very small contact area between the chip and tool, which in turn produces exceptionally high pressures and local temperatures. The second characteristic involves the segmentation of the chip, which is related to the relative rigidities of the workpiece, machine tool, fixture, and cutting tool, as will be discussed further presently.

Figure 7 shows another type of information that has been useful in metal cutting analysis. This figure shows the stainless chip formation specimen of the previous figure along with micro-hardness indentations which appear as diamond-shape impressions at two positions near the machine surface, and also in a line from the base of the work material up to the shear zone into the chip itself, and also within the built-up edge. This type of information indicates that it is possible for the hardness, and therefore the strength of a work material, to be increased by as much as one hundred percent as a result of a cutting operation. That is to say that the work material which comes off in the form of a chip has been so severely strained that it will be hardened to a terminal value. This does not necessarily mean that the finished machine part has been similarly altered, although a superficial layer of the machined surface may be severely strained so that on the one hand it may be stronger and more wear resistant, or on the other it may actually be severely weakened to such an extent that the load carrying capacity of the part may be adversely affected.

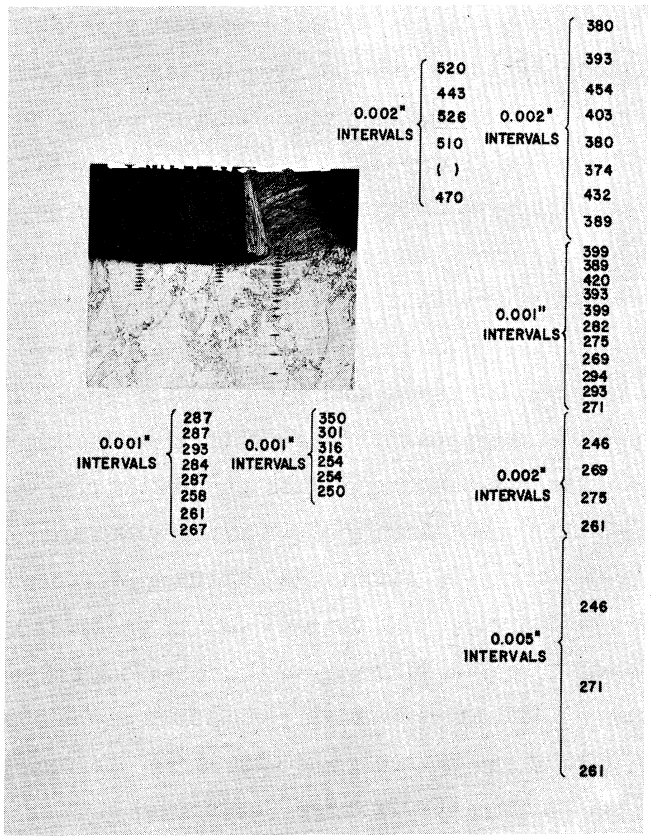


Fig. 7. Tukon hardness of cutting region for Type 304 stainless steel. Cutting conditions: same as Figure 6. Tukon operation: 100 gram load, Knoop Penetrator. Tests made on same section of Type 304 stainless steel shown in Figure 6.

Figures 8 and 9 show additional metallographic information on chip formation for pure titanium and two titanium alloys. Figure 8 shows profiles of the machined surface at the beginning of a shaper type of cut with cutting tools having different rake angles. It will be noted that the 15-degree negative rake angle produces a substantial thrust force which causes the entire system of machine tool, cutting tool, fixture and workpiece to deflect substantially, thus causing the cutting tool to remove a lesser thickness of metal shortly after the beginning of the cut. This effect is appreciably attenuated with a zero rake angle tool, as shown at the center of Figure 8. At the right in Figure 8 it is evident that the 20-degree positive rake cutting tool produces relatively small differences or changes in depth of cut, but is accompanied by oscillations in depth which indicate vibratory motion resulting from the shock of the initial contact of the cutting tool with the workpiece.

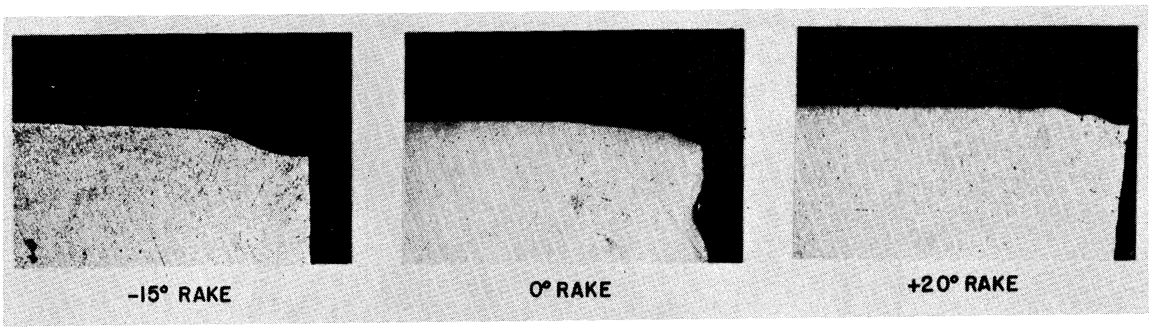


Fig. 8. Entrance conditions (shaper cut) versus rake angle for Type 130 B titanium alloy, using finish ground tools. Cutting conditions and work piece are the same as in Figure 6. Magnification 50x.

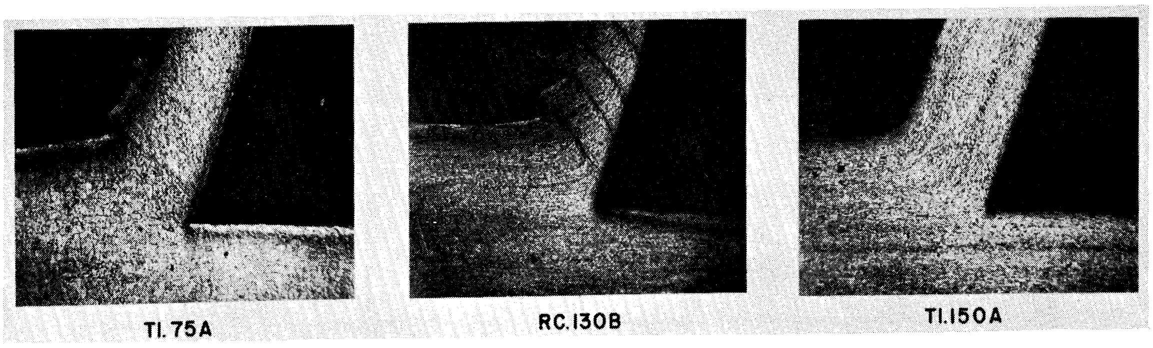


Fig. 9. Chip formation versus titanium alloy for alloys 75 A, 130 B, and 150 A. Cutting conditions: At end of shaper stroke, 4" stroke, 9 strokes per minute, 0.015" depth of cut, 0.250" width of cut. Back rake angle of tool, +20°. Magnification: 50x.

Figure 9 shows the actual chips obtained from chip formation specimens of pure titanium shown at the left in Figure 9 and two titanium alloys shown at the center and right in the same figure. The previous figure demonstrates the importance of cutting forces and their variation in a machine set-up of a given rigidity. On the other hand, the three different types of chip formation illustrated in Figure 9 demonstrate differences which arise from the notch sensitivity of metals in relation to rigidity and vibration characteristics of machine tools. The smooth continuous chip shown at the right in Figure 9 represents an ideal condition wherein the chip formation is continuous and where force pulsations are at a minimum. This condition usually gives rise to good surface finish and close control of size. On the other hand, the segmentation which appears in the chip shown at the center of Figure 9 is accompanied by substantial variations in cutting force which are reflected in surface finish and even in the size of the machined part. These segments which occur in the chip appear to be the result of vibrations of either the cutting tool or shock waves which are resonant vibrations set up by any sort of disturbance in the workpiece, cutting tool or other elements of the machine tool system.

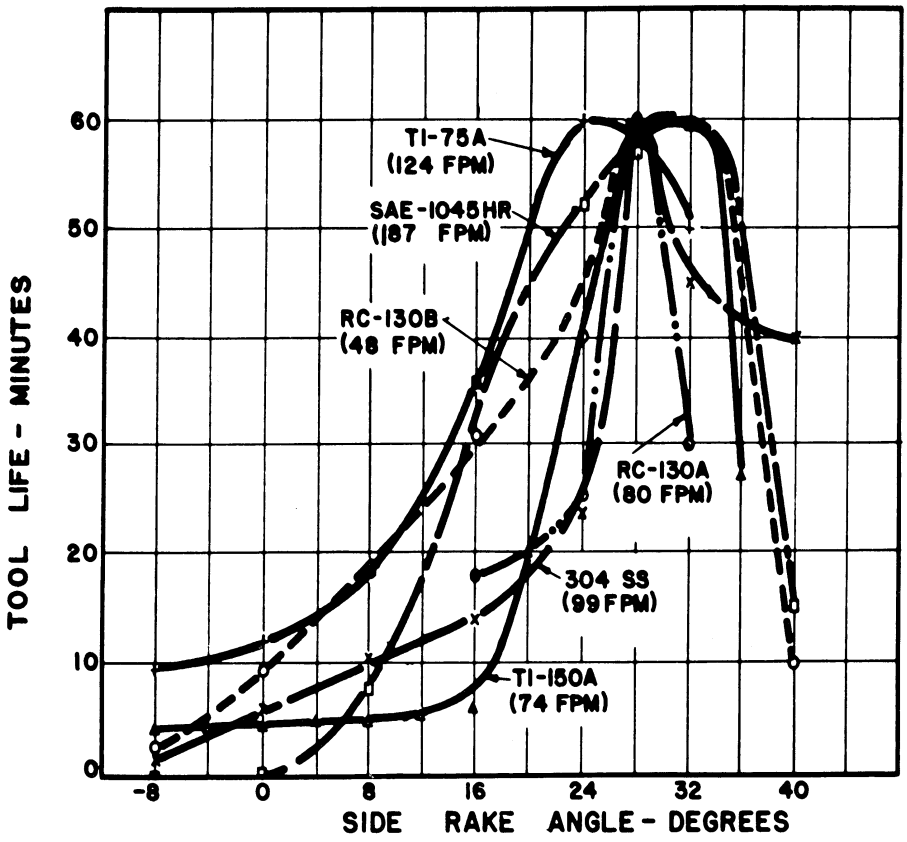


Fig. 10. Effect of side rake angle on tool life in turning for six materials. Tool material: 18-4-1 H.S.S. Feed: 0.006 IPR. Tool shape: 0, VAR, 6,6,6,15, 0.010". Depth of cut: 0.050". Cutting fluid: dry.

Figure 10 shows the relationship of tool life in a turning operation to the side rake angle of the tool for several different metals. Note that the tool life is increased substantially at higher rake angles and that it reaches an optimum for all of the metals in the vicinity of 28 degrees. At still higher rake angles the tool life drops off very rapidly. This is a result of spalling of the cutting edge, which is a manifestation of the brittleness of the cutting tool material and inadequate rigidity of the entire machine set-up. If the machine tool and the entire system were somewhat more rigid, then the optimum would be shifted to a higher rake angle; on the other hand, a less rigid machine would cause the optimum to occur at a smaller rake angle, perhaps in the vicinity of 16 degrees, and would result in a lower tool life at the optimum.

Friction, Wear, and Lubrication

Friction is a universal problem throughout the entire field of engineering. It plays a very important role in machine tools and in the metal cutting and plastic working

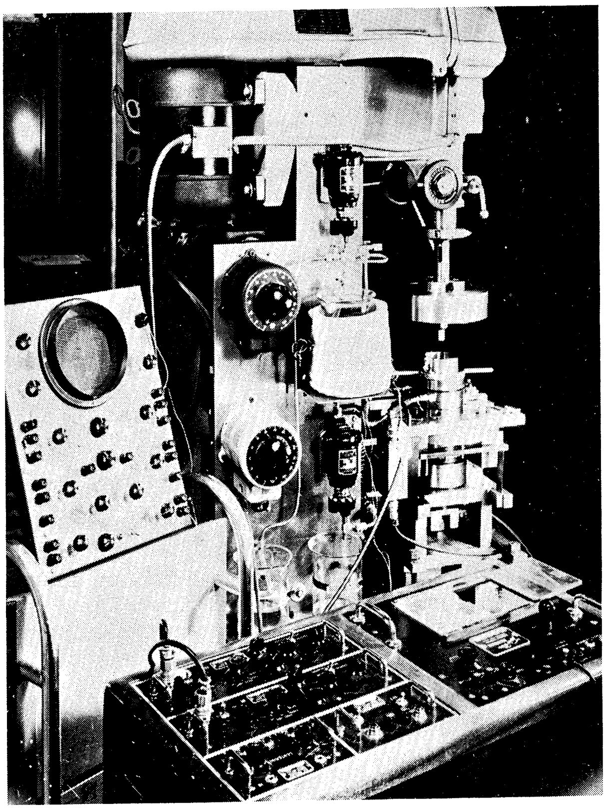
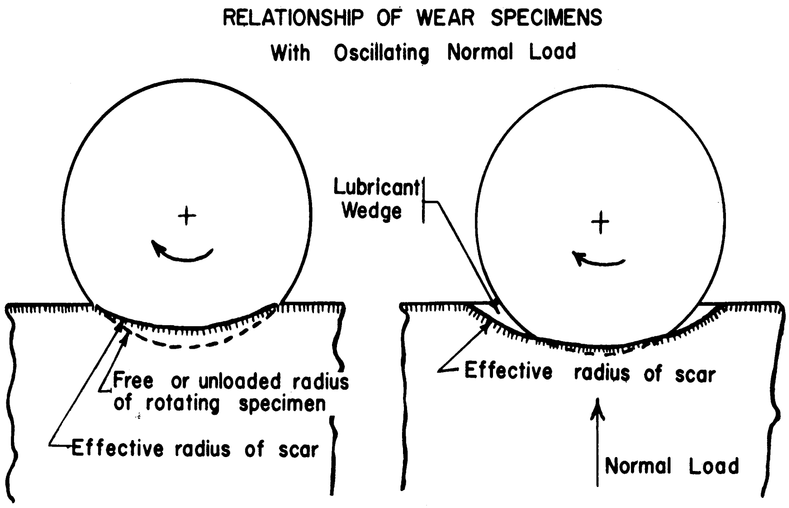


Fig. 11. A special machine for studying lubrication and frictional characteristics at conditions of extreme pressure, high rubbing velocities and over a range of temperature conditions. Tests carried out in this apparatus revealed that the elastic reaction to change in loads in bearing areas plays an important role in boundary lubrication.

processes in particular. Consequently the search for new information on the mechanisms of wear and lubrication has been carried out extensively in the area of metalworking processes, as well as on machine elements. Work here at the University has been concerned directly with lubrication and wear problems in metal-cutting and metal-forming operations, as some of the earlier Figures have indicated. However, we have also directed some of our efforts upon the mechanisms of friction itself, particularly at the extreme-pressure conditions which prevail in such operations.

Figure 11 shows a special friction and wear machine which was developed in the laboratories here about 15 years ago for analysis of the behavior of different types of cutting fluids at conditions of pressure, temperature, and rubbing velocities peculiar to metal-cutting operations. This was the second design in a series of three designs which have grown out of a succession of projects on friction and lubrication. This particular machine produced information which indicated that the elastic relaxation which takes place between metal parts with change in loading conditions plays an important role in the behavior of



(a)AT HIGH NORMAL LOAD (b)AT LOW NORMAL LOAD

Fig. 12. A lubricant wedge forms between rotating specimen and the wear scar as the normal load is reduced. Many shapes of the scar section are possible as the result of different rates of wear.

lubricants. It was this characteristic which led to the design of a third machine, now in use, which makes it possible to study the effects of elastic distortion of machine elements on the degree and nature of lubrication which is possible at conditions of extreme pressure.

Figure 12 shows schematically the principle which is carried out in the third design of friction wear machine now in use here at the University. Basically, the set-up involves a friction pair wherein one specimen is rotated while the other is pressed against it with a normal force which can be programmed to rise and fall linearly with elapsed time. The machine measures and continually records both the normal force and the frictional reaction in the form of a torque. The drawing at (a), at the left of the figure, shows an exaggeration of the conditions which prevail at the peak normal load. The normally circular rotating specimen is deflected from a circular condition, as indicated by the dashed line, to the solid line representing the interface between the two rubbing specimens. As the normal load is reduced, the condition shown in exaggerated scale at the right in the figure is developed. The elastic relaxation which results from reduction of the normal load causes a very narrow wedge to open up between the rotating specimen and the scar which has been worn in the other member of the pair. This wedge may be only a few millionths of an inch wide at its widest point so that penetration into the wedge depends strongly upon the mobility of the lubricant and also upon the size of the molecule, particularly where large or long chain molecules are involved, as is often the case with various additives to oil base lubricants.

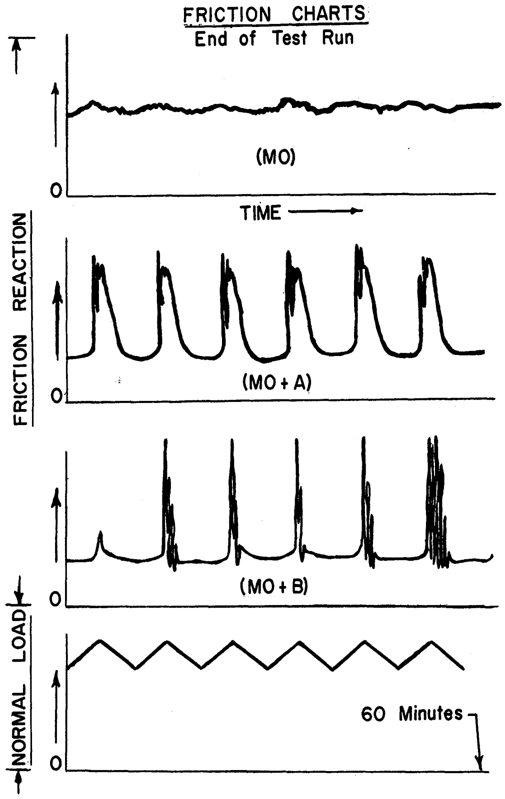


Fig. 13. Friction charts—end of test run. Typical results obtained from a friction-wear machine wherein the normal load is caused to vary periodically between maximum and minimum preselected values. The elastic relaxation which takes place upon reduction of normal load makes it possible to discriminate the relative effectiveness of two additives designated as A and B compared to the behavior of straight mineral oil designated as MO.

Figure 13 shows typical results obtained with the friction-wear machine operating with an oscillating normal load. This figure shows the results from the last six cycles of one-hour tests made with a mineral oil used both straight and with each of two different additives. The normal load was oscillated linearly with time, as shown at the bottom of the figure. The corresponding reaction friction forces for the three different lubricant conditions are shown in the three other records. Had the coefficient friction remained constant, the torque or friction reaction records would have had the same shape as the normal load record shown at the bottom. However, it will be noted that they were quite different. For example, the straight mineral oil produced substantially constant friction torque regardless of the normal load. This was due to the fact that a state of seizure persisted at all loads, both high and low, which represented a frictional force that could not exceed the sheer flow stress of the metal. Consequently, the frictional force did not increase with normal load, and furthermore the lower normal load was not sufficiently low to prevent seizure; therefore it resulted in the same frictional force.

On the other hand, both additives did penetrate the lubricant wedge illustrated in Figure 12 at the lower normal loads and succeeded in producing quite effective lubrication. At the highest normal loads however, both additives A and B were completely excluded to the extent that catastrophic seizure again took place. It will be noted that additive B was somewhat more effective than additive A. It was impossible to determine at the time the tests were made whether this was due to greater mobility or to differences in rate of wear.

The application of basic principles of lubrication to metal cutting requires attention to certain essential features of the metal-cutting process itself. The essential features which must be considered are shown schematically in Figure 14. Attention is called to three zones designated respectively by the letters A, B, and C. Zones A and B are areas of rubbing wherein conventional friction processes or mechanisms prevail. On the other hand, Zone C is the region wherein the metal is distorted in a shearing type of action and wherein no conventional interface exists where orthodox lubrication could take place. In the latter zone, theory indicates a remote possibility that gases of various types might be able to penetrate through micro-cracks. Thus, through corrosive or anti-weld action, they could reduce the energy required to shear the metal and thereby reduce both forces and heat generation. However, this zone presents the least likely opportunities for lubrication.

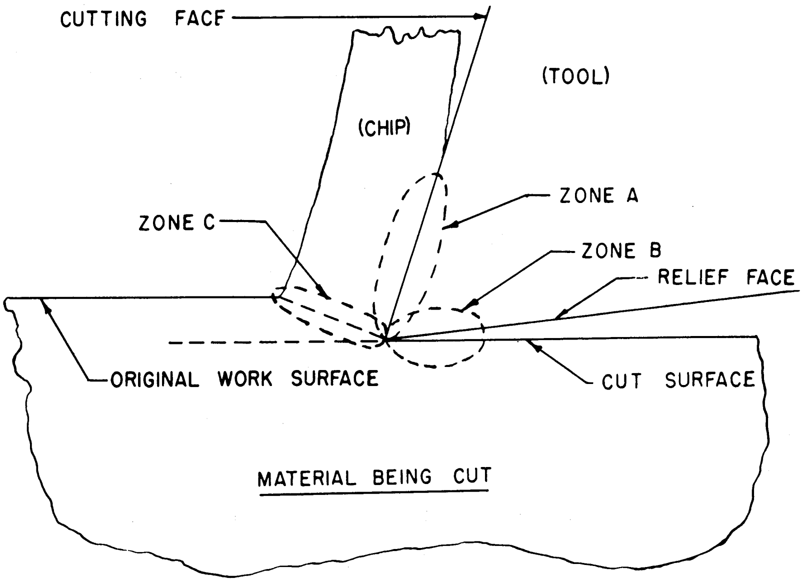


Fig. 14. A schematic of idealized chip formation identifying three zones of prime significance. Zones A and B involve rubbing contact between the cutting tool and work material; both may be regions of high temperature and represent the areas where significant wear takes place. Zone C, the shear surface, is a major source of heat.

Zone A is the chip-tool interface wherein friction accounts for as much as 30% of the total energy required to cut metal. Consequently, there are worthwhile advantages to be derived from accomplishment of effective lubrication in this zone. However, the rubbing velocities are high and the pressures range from at least 100,000 pounds per square inch up to as much as half a million pounds per square inch, depending upon the metal being cut. Furthermore, temperatures in this zone can be high enough to melt the work material. These rather commonly occurring conditions represent a real challenge for lubrication.

Zone B is the relief or clearance zone between the flank of the cutting tool and the cut surface which has just been created. Despite the deliberate provision of a relief space, the elastic relaxation which takes place as the cutting force moves past any particular point causes actual rubbing between the machined surface and the relief face. Rather little is known about the actual pressures which occur in this rubbing zone, although it is well known that substantial wear of the cutting tool can and does take place in this zone, particularly in the case of tungsten carbide and ceramic cutting tools. Zone B represents the best possibility and therefore the most fruitful opportunities for lubrication of the three discrete zones in metal cutting. The need for lubrication in Zone B and, consequently, the potential benefits of effective lubrication are especially significant in the cases of such operations as thread cutting by tapping, gear cutting, reaming, broaching, and some other metal-cutting operations wherein the relief angle is necessarily small and sometimes even zero.

Figure 15 shows an example of the lubricating problems in Zone B of Figure 14. This is a typical torque record such as might be obtained from either reaming or tapping, wherein the relief angle is necessarily small or non-existent. In the absence of lubricant, the torque would be quite low, as indicated by the level T_1 in the figure. This would be caused by the fact that a certain amount of loading or built-up edge would form on the tool point and actually cause the tool to cut somewhat oversize and even remove a greater amount of metal. However, this prevents the elastic relaxation (which takes place after the cutting edge goes by) from producing rubbing of the metal on the flank of the cutting tool in zone B. Consequently, the torque record for dry cutting would be a straight horizontal line at the level T_1 in this figure.

An effective lubricant for a reaming or tapping operation plays a dual role. First, it must remove or at least minimize the tool loading or built-up edge so that the correct size will be maintained in the operation. This will make it possible for the metal to relax against the tool flank in Zone B, thus creating some additional cutting force or torque, as in this case, the amount of which will depend upon the ability of the lubricant

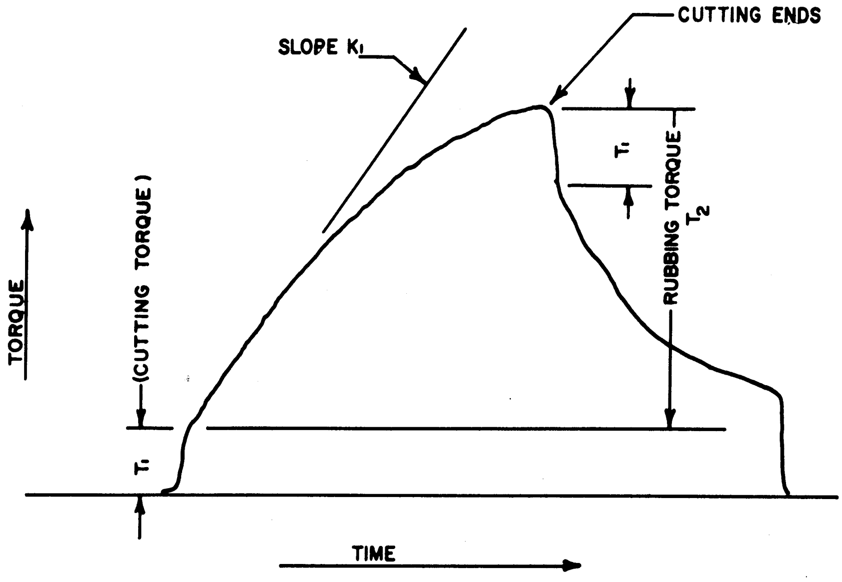


Fig. 15. Typical torque-time chart for reaming when rubbing occurs. Deviation from linear trend is due to plastic flow or burnishing in the presence of an effective lubricant. Torque for dry cutting remains constant at T_1 level. Dry reaming creates residual tension in peripheral direction. Dominant compression accompanies the high rubbing torques observed with some lubricants.

to reduce friction between the workpiece and the flank of the cutting tool. Figure 15 represents a typical torque record of a fluid which did eliminate the built-up edge and subsequently succeeded in lubricating in Zone B, at least to the extent that seizure did not occur. However, it is noteworthy that the maximum torque in this well-lubricated operation is several times as great as where no lubricant at all was used and wherein poor finish and poor size control would be the result. Thus, one arrives at the rather unusual conclusion in this case that an effective lubricant may increase force and energy requirements several times. This is often necessary where good surface finish and good size control are more important than the cost of the electric power.

Figure 16 illustrates how the lubricating characteristics of the type illustrated in the previous figure changed with size of cut. One can see that the torque required actually to remove the metal did increase linearly with the feed rate, as might normally be expected. On the other hand, the maximum rubbing torque decreased very rapidly as the size of cut increased, thus indicating that the lubricant lost its ability to prevent the formation of the tool loading or built-up edge. This again leads to the rather paradoxical result that the power required to cut decreases as the size of cut increases. More important, however, is the fact that surface finish and size control have deteriorated as the power requirements decreased.

INCREASING SIZE OF CUT WITH SHARP REAMER

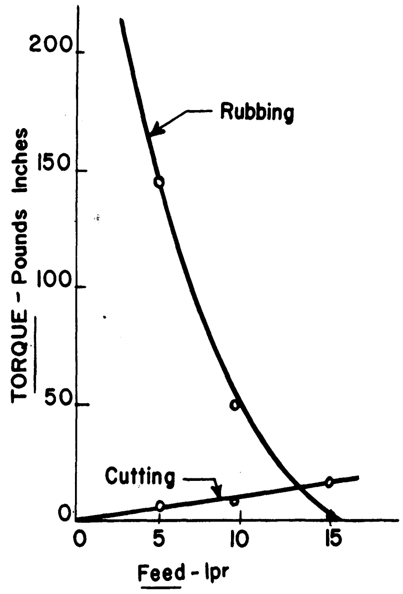


Fig. 16. Increased feed with sharp reamer on C 1045 steel resulted in considerable reduction of rubbing torque as size of built-up edge increased. Finish also deteriorated. Lubricant: Cimcool Concentrate. Initial hole diameter: 0.745 inches.

Ultrasonics

Several phenomena which result from the application of ultrasonic vibrations have been of special interest to some of the staff of the Mechanical Engineering Department here at the University. In the metal processing areas this has involved the application of ultrasonics to such operations as grinding, turning, planing, tapping, and even wire drawing. In all of these, there has been a rather spectacular reduction of friction as a result of the vibrations. These are relatively high frequency vibrations involving very small amplitudes. The frequencies have been in a range from 11 kilocycles up to approximately 25 kilocycles, while the amplitudes have ranged from 7 thousandths of an inch on down to only a few millionths of an inch.

Isolated tests have indicated reductions in frictional forces up to as much as 90%. In addition, there have been substantial improvements in surface finish, considerable change in chip formation, and in grinding a very favorable reduction in temperature and residual stresses.

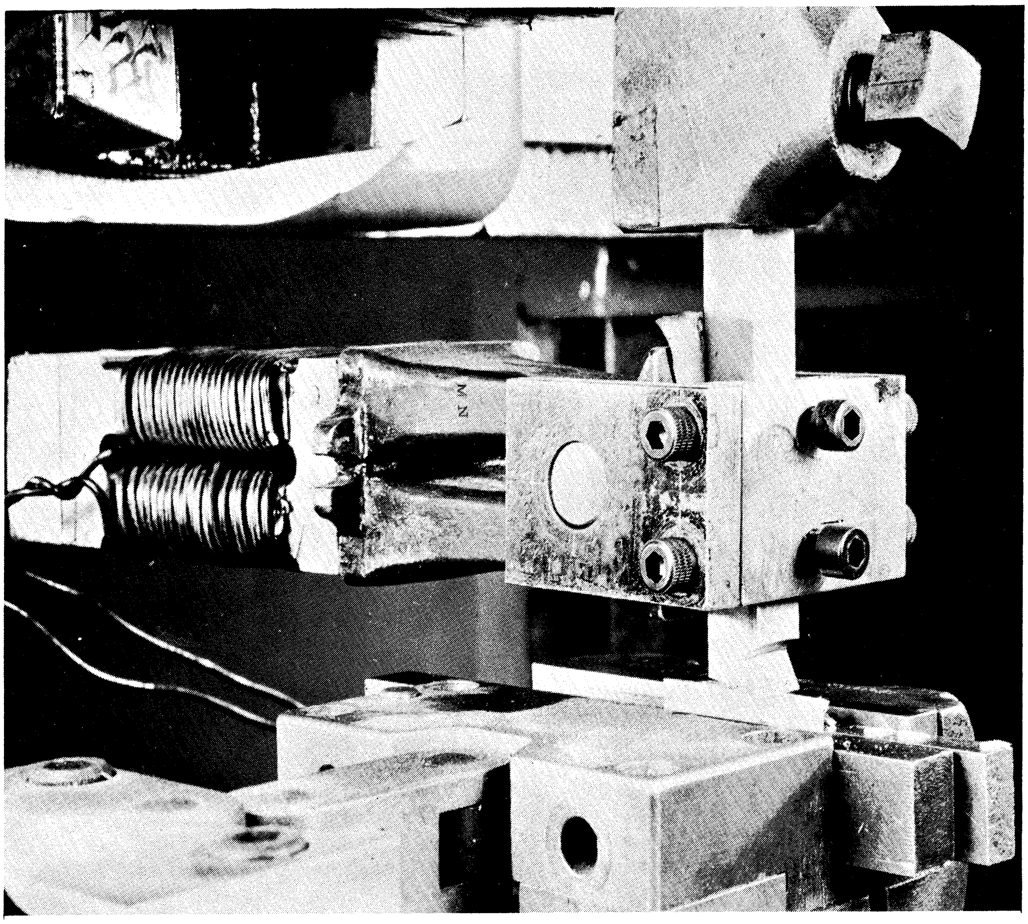


Fig. 17. A magneto-strictive transducer with a cast bronze horn is clamped to a 1/2" square high-speed steel tool bit mounted in an open side planner. It was intended that the transducer produce a vibration in the direction of cutting, although measurements indicated an elliptical motion resulting in helical chip formation. Ultrasonic vibration at 13 kilocycles produced better finish, closer size control, and a substantial reduction in force.

Figure 17 shows a set-up in a planer wherein a half-inch-square high-speed steel tool bit has been extended an unusual distance beyond the tool holder to permit a magneto-strictive transducer to be clamped just above the cutting edge. A piece of one-eighth-inch thick, dead-soft aluminum plate is clamped in the place beneath the cutting tool. The application of vibrations produced the change in chip formation illustrated in Figure 18. The chips shown at the right of Figure 18 are typical of those obtained at slow speed with a soft aluminum. They are greatly foreshortened and are accompanied by very poor surface finish which is characterized by erratic tearing of the machine surface. On the other hand, superimposed vibrations at a frequency of about 13 kilocycles produced the series of remove all of the material so that the chip remained on the workpiece. In all three instances the cutting conditions were identical with reference to the size of cut.

From right to left in the figure, the three different work materials are stainless steel, low carbon steel, and a titanium alloy, respectively. The stainless steel shown at the upper left produces a continuous chip with a built-up edge or tool loading between the underside of the chip and the cutting tool, which was located to the left of the chip.

Essentially the same behavior is evident in the cutting of the low carbon steel as shown at the center of the figure, except that the chip is very much thicker and appears to be broken, although it is actually a continuous chip that was severely segmented, thus appearing to be disconnected in the illustration. As in the case of the cutting of the stainless steel and the titanium, the cutting tool was located at the left of the chip, indicating that a crack preceded the cutting edge. This can occur as the illustration demonstrates, but this is but one phase in a pulsating process wherein the chip stops or refuses to slide along the cutting tool, thus shearing ahead of the work surface. The fact that we were able to obtain this particular condition is something of a fortuitous accident, since that portion of the chip in contact with the workpiece at the lower level is in the act of buckling just prior to the renewal of motion of the chip along the cutting tool.

The chip formation for the titanium alloy illustrated at the upper right in Figure 6 demonstrates two points of significance. The first is that the very thin chip relative to those produced by the stainless steel and low carbon steel gives rise to a very small contact area between the chip and tool, which in turn produces exceptionally high pressures and local temperatures. The second characteristic involves the segmentation of the chip, which is related to the relative rigidities of the workpiece, machine tool, fixture, and cutting tool, as will be discussed further presently.

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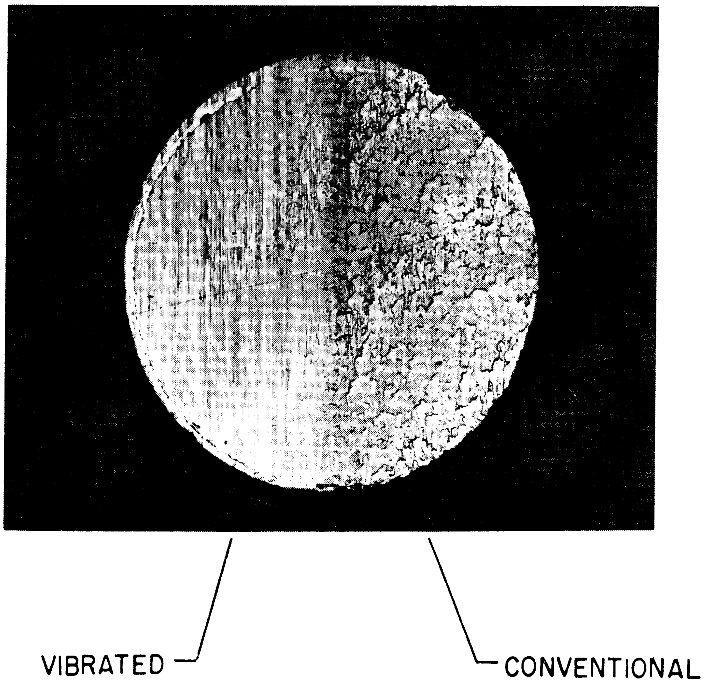
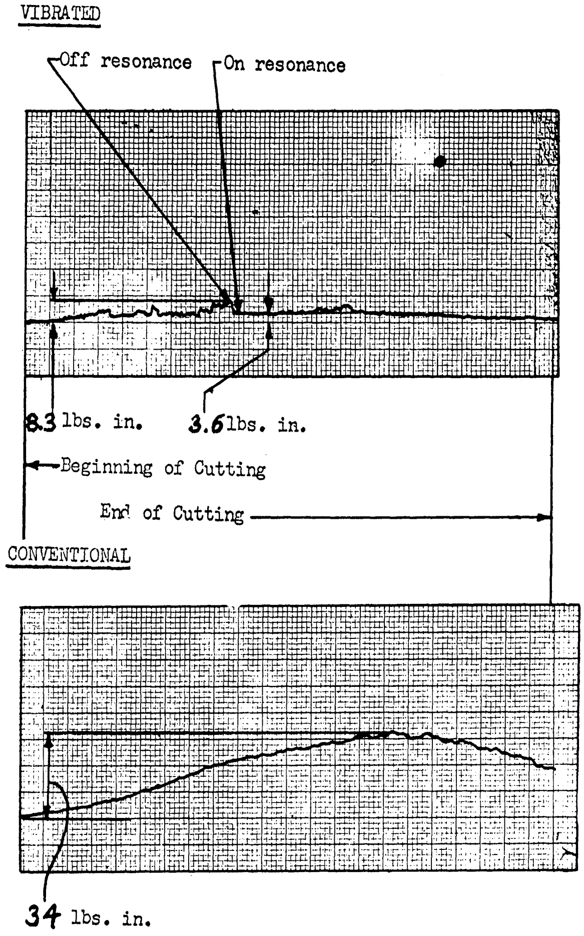


Fig. 19. Improvements in surface finish resulting from applying ultrasonic vibrations during a turning operation with high-speed steel on a low carbon steel work material. The magneto-strictive transducer was coupled to the side of the cutting tool through a film of castor oil to induce vibration in the feeding direction parallel to the axis of rotation.

the magnesium illustrated in this figure. The normal behavior is shown in the torque record at the bottom of the figure, wherein the torque rose to a maximum value of 34 pounds inches when no vibration was applied. The maximum rate of metal removal was achieved in the first ten millimeters of chart record, reading from left to right. The additional torque was due to rubbing on the flank of the tap caused by the exceptional elastic relaxation peculiar to metals with low modulus of the elasticity and low tendency toward built-up edge formation.

The superimposition of ultrasonic vibration at a frequency of about 25 kilocycles produced the records shown at the top in this figure. The frequency of vibration was adjusted manually at the oscillator and was deliberately adjusted off resonance at odd intervals. However, it can be seen that when it was held at resonance the torque remained constant at 3.6 pounds inches, or a little more than 10% of the maximum achieved when the high frequency vibration was not present. The vibration in this case was relatively strong and did result in some plastic distortion of the thread elements. However, the full amount of the metal was removed and the torque reduction can be attributed in substantial measure to an effective reduction in frictional energy.



MATERIAL: Magnesium

Fig. 20. The application of ultrasonic vibrations at 25 kilocycles in a longitudinal direction in the tapping of threads and magnesium, reducing the maximum torque from 34 pounds inches to 3.6 pounds inches. A sulphur-chlorinated cutting fluid was used for the 1/4" - 20 tap on both tests. Input power to the magneto-strictive transducer was less than 300 watts.

In 1953 we began a series of studies involving the application of ultrasonic vibrations to the grinding process. This was the result of a preliminary investigation into the effects of vibration on grinding wherein it was understood that vibrations were undesirable and that further investigation might yield information on how to cope with such vibrations. It quickly became evident that vibrations in the ultrasonic range could be advantageous even in grinding. Therefore the instrumentation illustrated in Figure 21 was developed

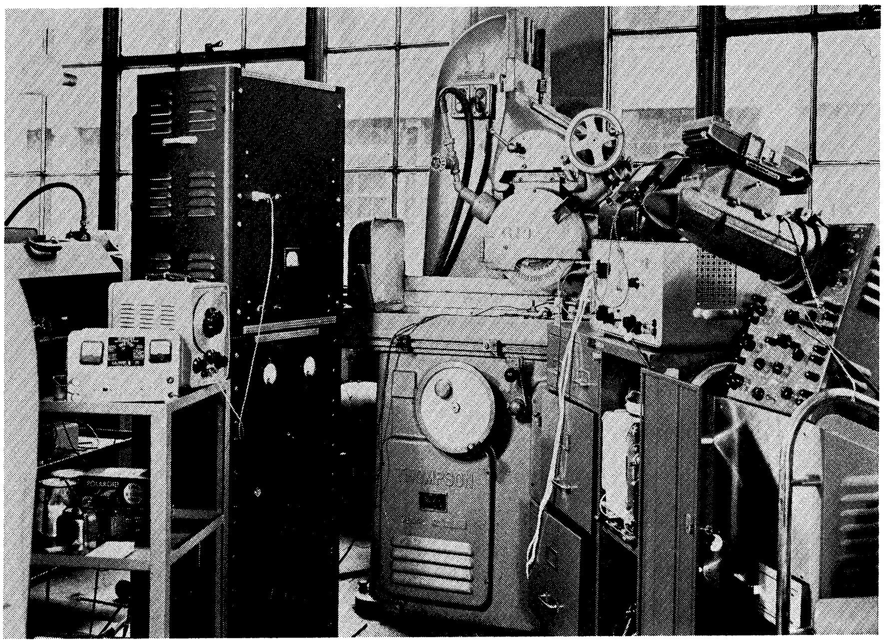


Fig. 21. Equipment and instrumentation for superimposing ultrasonic vibrations upon surface grinding. Direct current power source, oscillator and power amplifier of the ultrasonic generator are illustrated at the left. Thermocouple amplifier, input watt meter and dual beam oscilloscope with recording camera are shown at the right of the surface grinder.

Fig. 22. Close-up view of the grinding specimen mounted on top of the magnetostrictive transducer clamped at nodal points to the table of the surface grinder. The thermocouple imbedded in the underside of the work specimen is led out through the ceramic insulators shown at the right. Work piece oscillates alternately from right to left underneath the grinding wheel.

for the purpose of analyzing the effects of vibration during surface grinding. A close-up of the magneto-strictive transducer and a specimen workpiece with an imbedded thermocouple is shown in Figure 22. The specimen workpiece was cemented by epoxy resin to a supporting base which in turn was fastened to the upper end of a magneto-strictive transducer consisting of nickel laminations.

Figure 23 shows a typical time-temperature record obtained with the laboratory set-up illustrated in the previous figure.

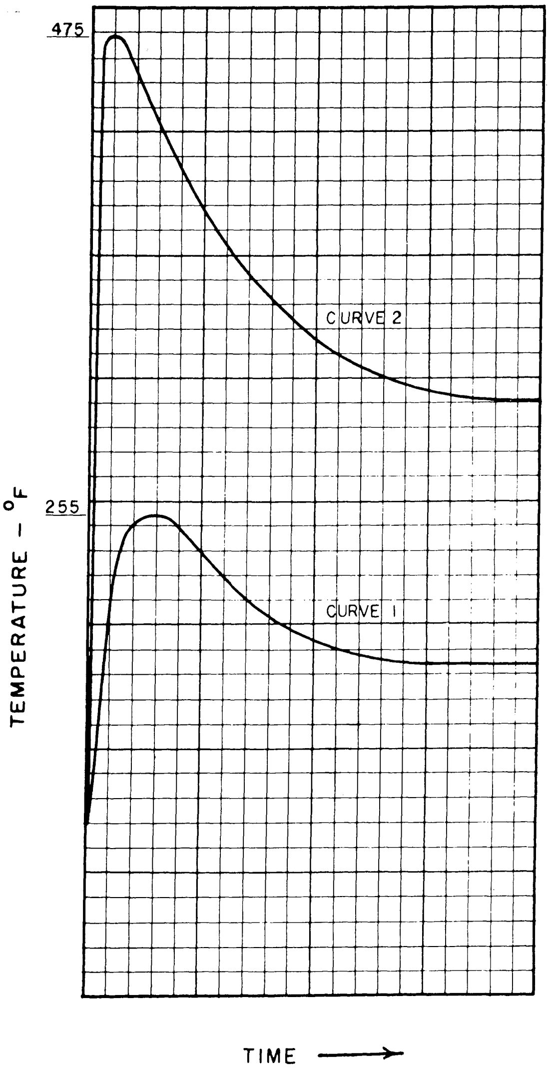
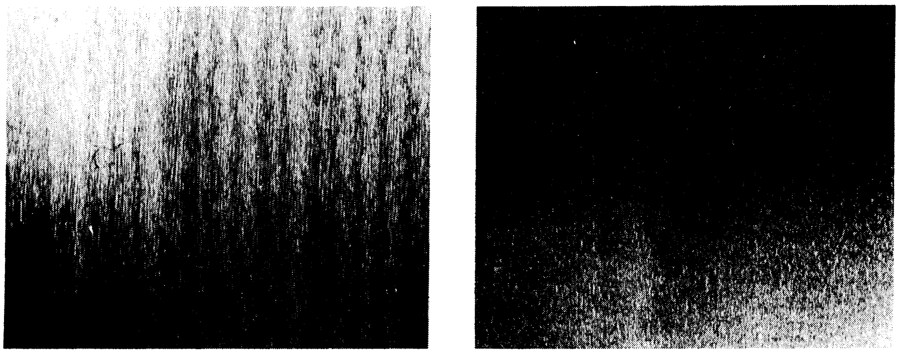


Fig. 23. Temperature time records as obtained with an oscilloscope camera for surface grinding cuts made with vibration (Curve 1) and without vibration (Curve 2). Material ground: AISI 4340 steel. Depth of cut: 0.002 inches per pass. Feed velocity: 60 F.P.M. Vibration frequency approximately 25 kilocycles; vibration amplitude approximately 0.0005 inches.

It will be noted that the peak temperatures (on the Fahrenheit scale) without vibration differed by almost 2 to 1. The temperature curve obtained for vibration is designated as curve 1 in the figure, while that without vibration is represented by curve 2. These were successive cuts, and the actual depth of cut was approximately 30% greater for the pass made during vibration. The reasons for the beneficial effects of the vibration upon surface finish and other factors discussed later were analyzed in a technical paper presented before the American Society of Mechanical Engineers in June of 1955.

Figure 24 shows photographs of two full-hard specimens of AISI 52100 steel ground as shown at the left, at conventional conditions, and also conventional conditions, except for the superimposition of ultrasonic vibrations, as shown at the right. The surface obtained with vibration was very highly reflective and therefore necessarily appears relatively dark in the illustration. It will be noted that the specimen which was ground conventionally without vibration is characterized by somewhat irregular dark streaks which appear in a vertical direction on the surface as shown at the left. These darker streaks are oxides which are caused by the higher temperatures peculiar to the regions in which they occur. This is another indication that lower temperatures prevail when ultrasonic vibrations are superimposed on grinding operations.

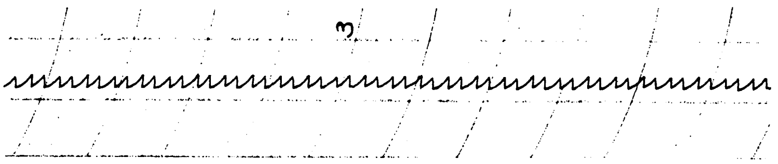


CONVENTIONAL VIBRATED

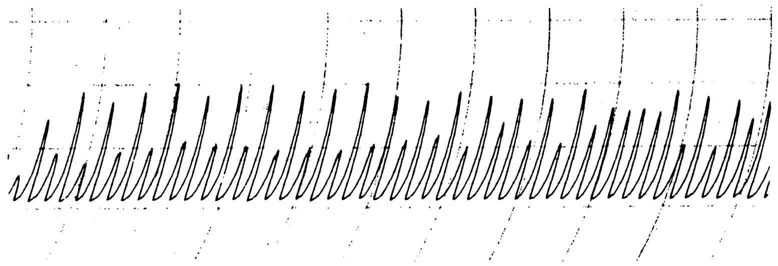
Fig. 24. Photographic reproductions of surfaces of AISI 52100 steel ground in the full hard condition. The specimen, whose ground surfaces are shown at the right, was vibrated at 25 kilocycles with an amplitude somewhat less than 375 millionths of an inch. Note the appearance of lines or streaks of dark oxides created by the high temperatures on the specimen ground at conventional conditions without vibration.

Further evidence of the beneficial effects of high-frequency vibrations superimposed on grinding are illustrated in Figure 25, wherein chart records from the input wattmeter to the spindle of a surface grinder are reproduced for several conditions. The record appearing at the top is typical of that obtained for a freshly dressed grinding wheel used

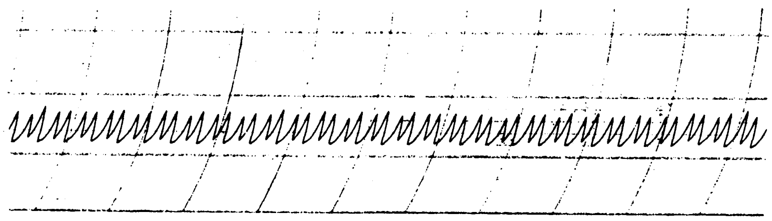
POWER REQUIREMENTS IN GRINDING AT VARIOUS CONDITIONS OF VIBRATION



POWER REQUIREMENTS ON THE INITIAL PASSES



POWER REQUIREMENTS WITHOUT VIBRATION (AFTER THIRTY PASSES AND BEFORE THE SECOND DRESSING)



POWER REQUIREMENTS WITH VIBRATION (AFTER THIRTY PASSES AND BEFORE THE SECOND DRESSING)

Fig. 25. Power requirements in grinding at various conditions of vibration. Watt meter records of power input to the spindle of a surfacing grinding machine. Power requirements on initial passes represent the minimum requirements for a diamond dressed wheel. Power after 30 passes without vibrations demonstrates greater requirements when work piece is moving against the direction of grinding wheel rotation. Material ground: hardened AISI 52100 steel. Depth of cut: 0.002 inches. Cross feed: 0.025 inches per stroke. Work velocity: 60 F.P.M.

for surface grinding both with and without vibrations, thus indicating that the vibration had no noticeable effect where the frictional rubbing and resultant heating was absent. The record at the center of the figure shows the input power requirements at the spindle after grinding 30 successive passes. The peak power requirements have increased substantially, and it will be noted that there is approximately a 2 to 1 ratio in the power required, depending upon whether the workpiece moves in the direction of grinding wheel rotation or against it. The power is lowest when the movement of the workpiece is in the same direction as the rotation of the grinding wheel. This is analogous to the well-known climb milling condition in milling machine operations as contrasted to the conventional milling machine cut.

It will be noted that the peak power requirements after the dulling of the grinding wheel have increased to almost 20 times that required by a sharp wheel. Consequently one would expect that other means which could effectively reduce friction would also minimize this increase in power. The wattmeter record at the bottom of the figure illustrates that the superimposition of ultrasonic vibration does indeed hold down the increases in power requirements resulting from the dulling of the abrasive grains in a grinding wheel. Furthermore, it will be noted that the differences in power requirements resulting from differences in direction of motion of the workpiece are practically eliminated.

Figure 26 illustrates the ability of ultrasonic vibration to reduce the warping and residual stresses resulting from a grinding operation. Specimens of a high-temperature refractory metal two inches square by five-sixteenths inch thick were used. They were surface ground at constant conditions, except for the alternate superimposition of ultrasonic vibration. The curvature of the work surface both before and after grinding was carefully measured, both in the direction of grinding and across the direction of grinding,

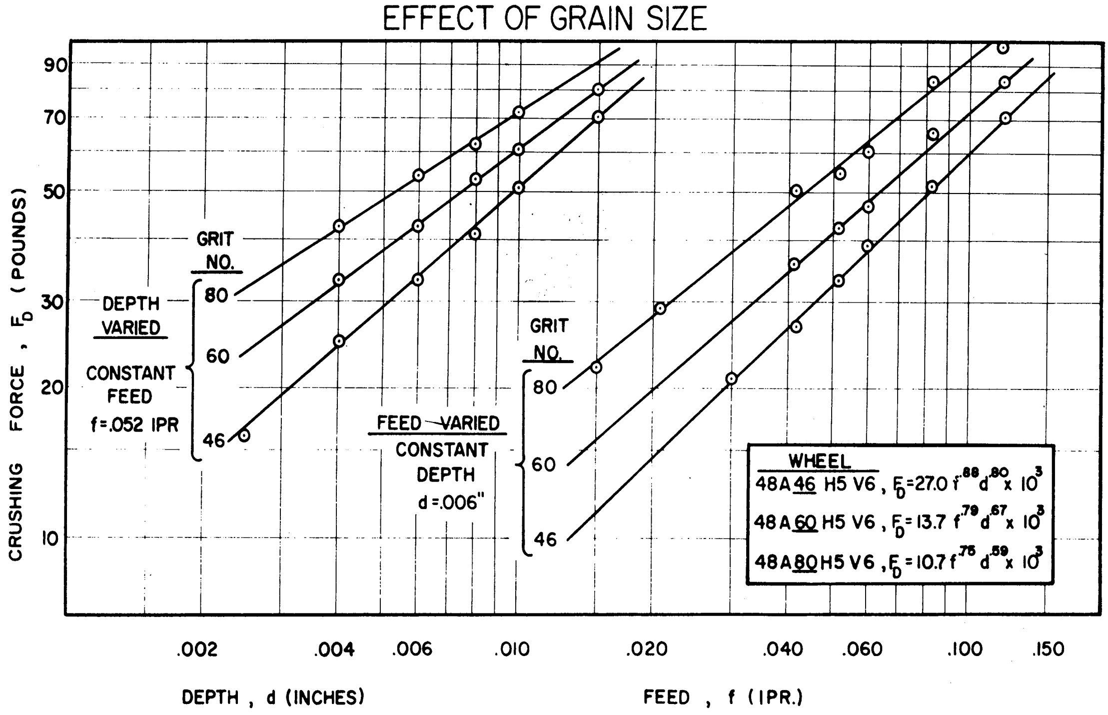

EFFECT OF GRAIN SIZE

Fig. 26. Warping in thin parts that have been surface ground indicates dependency on the shape of the heat source. Small down feed creates a substantially circular source, while large down feed and rubbing across the wheel face causes the shape of the source to approach a straight line. This property is demonstrated for conventional grinding by curves at left. Superimposing ultrasonic vibration prevents formation of line sources.

which is in the feeding direction. The results obtained from those tests made without vibration indicate that substantial contact was made between the work specimen and the grinding wheel across the entire face of the wheel, thus resulting substantially in a line source of heat which caused considerable warping in a plane parallel to the direction of grinding, and appreciably less across that direction.

On the other hand, when ultrasonic vibration was applied, the distortion resulting from the high temperatures of grinding was only slightly greater in the cutting direction than it was in the feeding direction, thus making it logical to characterize the heat source as substantially elliptical. This indicates that there was very little rubbing between the workpiece and the grinding wheel in regions remote from the side of the wheel where most of the grinding takes place. It is further significant that the application of the ultrasonic vibration approached a neutral stress condition at an appreciable depth of cut, 0.001 inches, whereas the conventional grinding reversed its trend at about the same depth of cut and produced even more severe residual tensile stresses at a still lighter cut, thus indicating that frictional heating is also quite sensitive to the rigidity of the entire grinding system.

Grinding Wheel Quality

The quality of the performance of the grinding wheel among other things depends heavily upon the strength of the wheel in relation to the dulling of the abrasive grains. As the grains become dull, the forces applied to the individual grains increase. Eventually the strength of the bond holding the grain into the wheel is exceeded and it will break out, thus exposing unused and sharper grains. A relatively low-strength bond will cause a wheel to wear too rapidly, while a very high-strength bond will retain the abrasive grains to a very high degree of dullness, thus resulting in excessive frictional rubbing, heating, and other undesirable effects. It is understandable then that any variation in the hardness or strength of the bond throughout the body of a new grinding wheel will give rise to variability in the performance of the wheel. Consequently, numerous investigators have been exploring this problem and hunting for dependable procedures for determining grinding wheel hardness and quality. This search has been going on more or less continuously for the last half century.

A little more than two years ago, an engineer and official of a Michigan grinding wheel manufacturing firm brought this problem to the attention of the University and suggested a possible approach to a solution of the problem. After preliminary investigation a group of three undergraduate students in mechanical engineering undertook a study which has given rise to a process that shows considerable promise of solving the problem and thereby benefiting both the producer and the users of grinding wheels.

Figure 27 shows a typical chart record which could be produced by this process from a defective grinding wheel. A dynamometer is used to obtain a measure of grinding wheel hardness or bond strength over the entire working surface of the grinding wheel. The dynamometer force which is proportional to the hardness is shown plotted vertically in the figure, with the resulting profile representing the hardness across the face of the wheel from the left side as shown at the left in the figure, across to the right side of the wheel as shown at the right in the figure. It will be noted that the left side of the grinding wheel was relatively hard, as indicated by a dynamometer force almost twice that which prevailed in the center of the wheel. Furthermore, the right-hand side was still harder and indicated substantial oscillations which when analyzed indicated that the hardness actually varied around the circumference of the wheel because of a continuous variation in hardness from one hard spot to a softer region. This was definitely a defective grinding wheel but it is typical of what can happen in relatively large wheels which are much more difficult to process. This technique has helped identify and overcome the causes of such hardness variations as are indicated in this record.

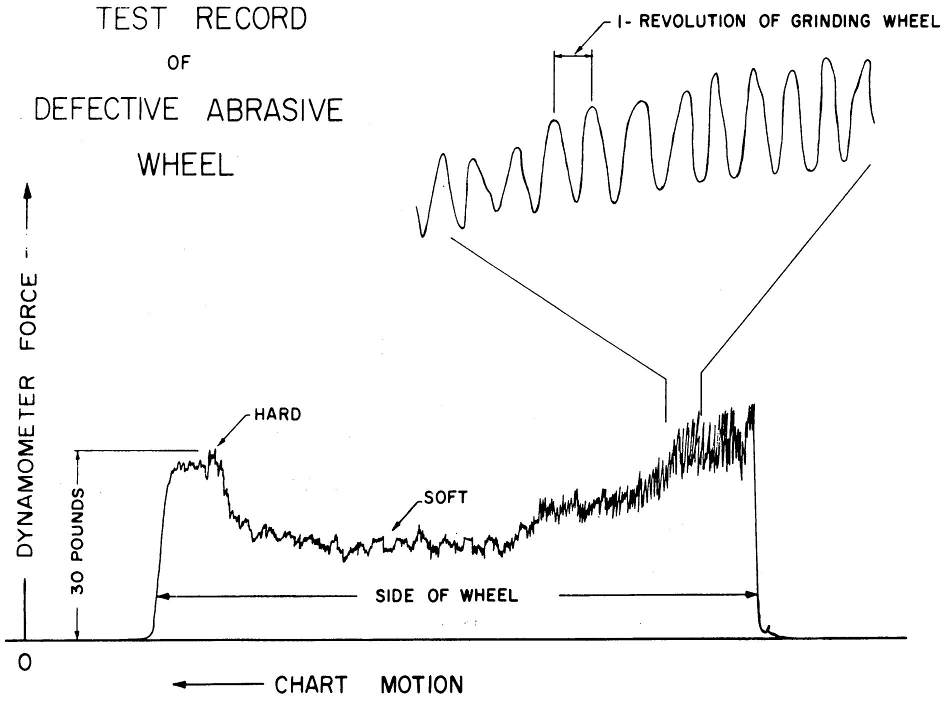


Fig. 27. A reproduction of actual test record for the circumference of a defective grinding wheel. Sides are hard and middle is soft. Right side shows variation of 20-25% in hardness around circumference. Time for test traverse = 23 seconds.

Figure 28 illustrates schematically the process and equipment which was used to obtain the record of the previous figure. The laboratory set-up developed for analyzing

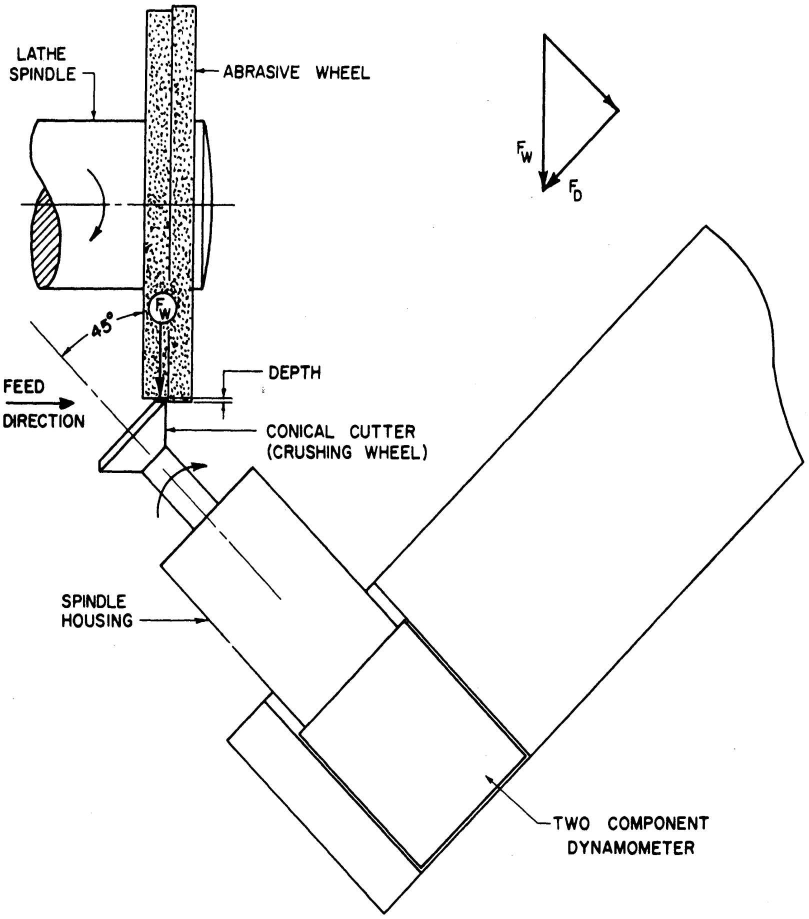


Fig. 28. A schematic of the laboratory test set-up. A dynamometer is mounted on an extension plate substituted for the compound of a modified 12-inch swing engine lathe. Depth settings are made with the cross-slide, and feeding is accomplished with the carriage. Vertical and horizontal force components are indicated on the chart of a Model 60 Sanborn carrier-amplifier-recorder. Crushing wheel is S.A.E. 6150 steel hardened to 54-56 Rockwell C-scale.

the process involved mounting a two-component force dynamometer equipped with a free-running spindle on the cross side of the lathe. A hollow steel cone mounted on the end of the free-running spindle is caused to roll against the surface of the grinding wheel as it also rotates. The reaction forces between the hollow conical cutter and the grinding wheel cause abrasive grains to be crushed out of the structure, thus changing the diameter of the grinding wheel. Thus a test is made by deliberately setting the conical cutter for a particular depth of cut or interference with the grinding wheel, and then feeding it laterally across the surface.

The force dynamometer measures the reaction forces, which in turn are proportional to the hardness of the wheel or the strength of the bond which retains the abrasive grains in place. The depth of cut can be of the order of magnitude of 0.003 to 0.006 inches for the testing of most grinding wheels. This procedure gives measurements which are very orderly and repeatable when the grinding wheel itself is uniform.

The force or hardness measurements obtained with the apparatus illustrated schematically in the previous figure are shown plotted on double logarithmic coordinants in Figure 29. Both the depth of cut and the feed rate were varied on three different wheels and the results plotted in the figure. The most significant feature of these data is their orderliness. It demonstrates that a repeatable test has been found.

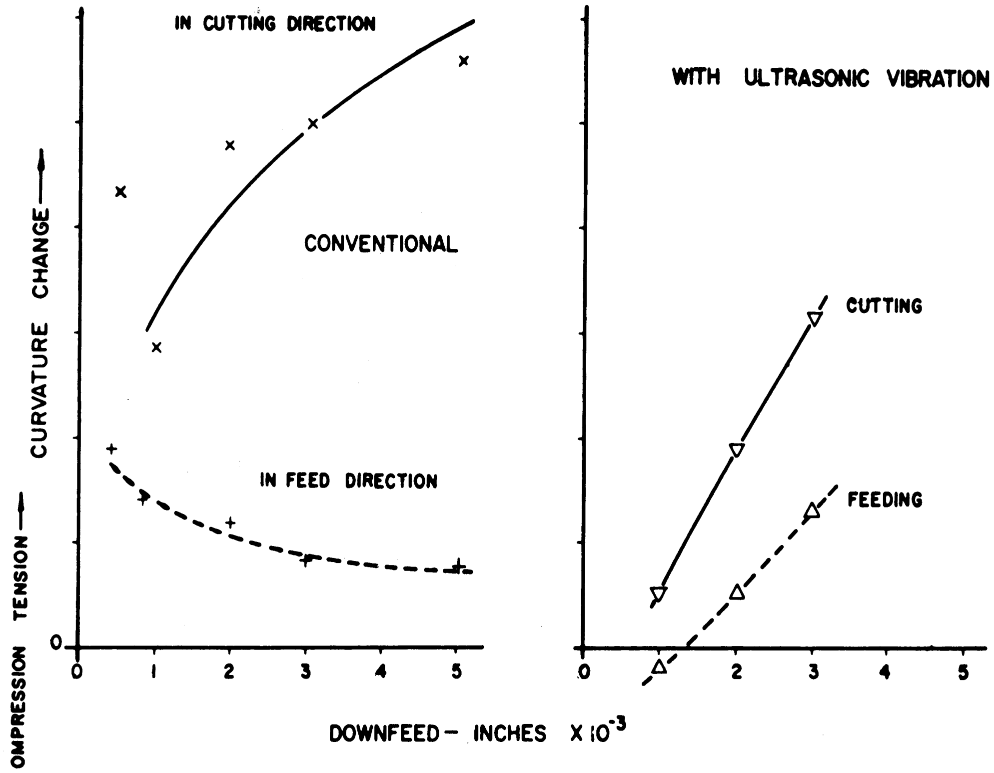


Fig. 29. Test results of 12 x 1 x 5 vitrified, aluminum oxide grinding wheels. All were made to the same specification except for grain size. Test points shown are the equilibrium averages of at least three consecutive tests. Vertical force component was negligible. Speed was constant at 700 rpm.

Interpretation of the results is as yet a matter of conjecture and therefore a problem for further research, particularly in developing the correlations of such information with actual grinding performance. Two technical papers have already been written on further analyses of this process. This particular problem was selected for this presentation because I believe it is typical of the progress which can be made even by undergraduate engineering students when they are made competently aware of challenging problems and given an opportunity to work on them even during the formal part of their undergraduate education.

Current Programs

I have presented a few highlights of some of the research programs carried out in the past and up to recent times. Currently we are carrying out similar studies over a broad area. These include tungsten machining, high-speed milling of high-strength alloys, cutting fluids, ultrasonics, and somewhat paradoxically a feasibility study looking toward the development of techniques for determining the sharpness of surgical scalpels.

Both our past activities and the current programs demonstrate the scope of the problems that we are confronted with in attempting to improve the equipment and the processes involved in manufacturing. The scope of the problems is exceedingly broad, and their depth is almost equally great; the detail cuts across the traditional boundaries of scientific and engineering subjects, necessarily involving the best of mathematics, physics, and chemistry, as well as all of the traditional branches of engineering. I have said very little about machine tools and manufacturing equipment per se. This is because we have done very little, but we should do much more. Up to this time, at least, we have found more than an adequate challenge in trying to solve the problems of metal cutting alone.

Summing up our experiences over the past 25 to 40 years of research in the manufacturing and metal processing area, it becomes abundantly clear that the progress we have made has depended more than anything else upon two things: (1) the utilization of the latest and best developments in instrumentation and techniques of investigation, and (2) the most advanced and most fundamental scientific bases of analysis. Much has been done, progress has been made, but much more remains to be done. We welcome your interest and suggestions. We need your support and in turn we hope our efforts will be useful in setting and attaining your objectives.

Section III

GENERAL UNIVERSITY RESEARCH CAPABILITIES

5

RESEARCH ASSISTANCE TO INDUSTRY

Robert E. Burroughs

Much has been said in and out of the University about research assistance to industry by the University. In this discussion, I plan to outline the type of assistance the University can give industry as a result of its research activities. Some knowledge of the salient aspects of the University's research activities will assist in understanding the possible contributions it may make to industry, as well as some of the limitations on those contributions.

The University's research program last year amounted to approximately thirty and one-half million dollars. Twenty-eight million of these dollars came from outside sources, principally the Department of Defense and other government agencies, private foundations, individuals who made research grants to the University, and members of industry. The industrially-supported research fell into two broad categories: research related to government prime contracts with the sponsor, and research connected with the sponsor's proprietary interests unrelated to a specific government contract. In these two categories, there were 120 projects aggregating approximately $1.3 million, representing 5% of our total research volume.

Research on a university campus differs in many respects from research conducted in an industrial laboratory. First of all, the interests of the faculty and staff determine the nature of the research, and their collateral duties (teaching, staff work, etc.) determine to a large extent the schedule of progress on the research. For this reason, contracts for research cannot be accepted by the University before determining whether or not there is interest on the part of the faculty and staff in performing the research. Over three-quarters of the projects resulted from proposals to sponsors which originated on the campus. The remaining one-quarter resulted from requests from sponsors to the University faculty and staff to submit proposals Proposals presented as a result of solicitation from the outside are submitted by individuals through the University's established procedures, only because the individual is interested in the work The University does not submit proposals and then assign a faculty member or staff member to the project.

All research undertaken in the name of the University of Michigan must be compatible with the University's objectives. The University is primarily an educational institution, and its research effort must contribute to its educational objectives. For this reason, the University does not undertake, in the name of research, testing, process trouble shooting, product development or redesign, or supply engineering services. Let me hasten to add, however, that because many of your requirements fall in these categories, do not assume that the University is not in a position to give you assistance, as will be seen in what follows.

The contributions of the University to the industrial development of the State will fall in several categories. I will discuss a few of these in a sequence starting with general contributions and working toward very specific contributions. The presence of the University in the State of Michigan and its continuing development resulting in the residence within the State of outstanding scientists and engineers will improve the State's scientific climate, and, therefore, nurture the establishment and development of new industries based on the results of research. There is a wealth of evidence that indicates that the concentration of this type of talent in an area has resulted in a very diversified industrial development that will provide a large percentage of the jobs in the future.

Research on subjects of industry-wide significance by the faculty and staff of the University represents another means of assisting industry. The programs of three agencies on the campus, the Bureau of Business Research, the Institute for Social Research, and the Institute of Science and Technology, are designed to yield information in this category. The results of their studies of this nature are available to you and, further, they invite your suggestions as to the type of research problems you are interested in. The staffs of these three organizations, together with others of the faculty and the staff of the Office of Research Administration, are all available to you to advise you on the applicability of research to your immediate problems. This is an important service which has not been utilized to date. Many industries, possessing very limited technical facilities and staff or none at all, are not in a position to evaluate the practicality of a research approach to questions bearing on their operations. You may arrange for this by communicating with the directors of the three organizations named above if you know that your question falls within their areas of interests; or, if you are uncertain concerning where such advice may most appropriately be given on the campus, you may address your inquiry to Dr. R. A. Boyd, Assistant Director of Research Administration, Office of Research Administration, The University of Michigan. The staff of that Office will arrange for discussions between you and the most appropriate members of the University staff. In such discussions you will be advised as to whether your requirements can best be met by the research approach, or whether it more properly falls within the field of services rendered by agencies other than the University.

In moving toward the more specific forms of participation and assistance to industry, I should mention the consulting services available by direct and private arrangement with members of the University faculty Members of the faculties of many disciplines are available to you in accordance with the University's policy which permits its faculty members to consult outside the University. While arrangements for consulting services are made privately between the industrial firm and the faculty member, the Office of Research Administration will assist you in locating those members of the faculty who are most likely to be in a position to render the desired assistance.

If discussions with members of the University faculty as referred to above result in a decision that, from both your point of view and the University's, research can be undertaken by the University faculty or staff with mutual advantage, there exists a procedure whereby you may contract with the Regents of the University for the research to be undertaken. Such contracts are of a cost reimbursement type. You pay only the actual costs made up of the direct costs of salaries and wages, materials, supplies and services, and an indirect cost amounting to 60% or 75% of the salaries and wages. The contract providing for ownership of patents carries the 75% indirect cost.

In the conduct of research supported by industry which usually has high proprietary values associated, the University takes appropriate steps to protect such values. Research reports on sponsored-research projects supported by industry are always considered by the University as having high proprietary value and the University will neither divulge proprietary information supplied by the sponsor, nor provide copies of the report to others without obtaining the sponsor's approval. These are the terms under which all of our sponsored research with industry is conducted. In this connection, the language of the University's contract form on the matter of publication is: "The policy of the University is to encourage staff members to publish significant results of project work that are in the nature of fundamental or general principles. Manuscripts based on the work of this project will be submitted to you before publication for approval of matter pertaining to your proprietary rights."

The patent provisions of the University contract state: "In the event that one or more developments which may appear to be patentable are made by University employees in the performance of this research work, the University agrees to give you a complete disclosure of data and information relating to such invention, as promptly as reasonably possible, and you shall have the option of electing to acquire ownership of a patent on each such invention at any time within six months after the date the invention is reported to you in writing."

Earlier it was indicated that the University will not undertake testing or evaluation.

While this type of activity is not compatible with the University's objectives it nevertheless will, to a limited extent, perform such services for Michigan industry when they are not available from an outside source, and when the University possesses the required facilities. The University does not desire to compete with organizations who provide services and products as a part of normal commerce. It has been our practice, and will continue to be our practice, when we receive inquiries concerning services which more appropriately should be rendered by others rather than the University to refer such inquiries to other organizations such as consulting firms, testing laboratories, engineering service organizations, etc.

In the above discussions the term "research" has been used broadly. We in the engineering and physical sciences are prone to consider research, unless further defined, as referring to these fields. This is not the case. The University's research program extends over all fields, and the contract procedures outlined above apply to all of these fields. Therefore, if you have an idea that the University, through its research facilities, may assist you, or if you would care to review with the University staff your activities in order to determine to what extent research might be of assistance, you will obtain help in locating the proper individuals by communicating with Dr. R. A. Boyd, Assistant Director of Research Administration, Office of Research Administration, at the University of Michigan.

Your future depends on research, whether you conduct it or someone else.

6

THE ROLE OF THE INSTITUTE OF SCIENCE AND TECHNOLOGY

Rune L. Evaldson

It is my privilege today to extend to you the welcome of the University and of our Institute of Science and Technology, and to wish you both a fruitful and pleasant visit to Ann Arbor.

I also wish to pass along to you the regrets of the Institute's Acting Director, Dr. J. T. Wilson, that he could not be with you. Dr Wilson is out of the country on travel associated with our seismics research program.

Mr. Bacon will soon discuss with you in some detail the plans and aspirations of this meeting, and I won't go into these now, except to note that it appeared desirable for us to tell you a little about the University's large and many-faceted research program, and to explore with you the ways in which this program might be made more useful to you and your companies, and therefore to the economic welfare of the State.

Before I turn in some detail to the activities of our Institute of Science and Technology, I wish to tell you a little of the over-all research program of the University.

Research is, and must be, a vital and integral part of the activities of a university such as ours. This research is carried out in many ways. At one end of the spectrum are the classical and fruitful efforts of the individual professor, working with his graduate students and with younger members of the faculty, as carried on in all of the teaching departments in our various schools and colleges. Then, again within the teaching departments, as programs grow larger and more complex, research is also carried out in both formally and informally organized research groups of many kinds, again with members of the teaching faculty and graduate students, but now in some instances augmented with full-time research personnel. At the other end of the spectrum we have organized research entities such as the Institute of Science and Technology and the Institute for Social Research, units that are organizationally separate from the schools and colleges although they work very closely with them. Here again the programs are carried out by full-time research and supporting personnel, by members of the teaching faculties, and by graduate students. Such institutes and centers have several reasons for being. They can, for example, provide convenient and effective administrative homes for activities that are interdisciplinary in nature, and therefore cut across the interests of several or many teaching departments.

All of the research activities come under the general cognizance of our Vice-President for Research, Dr. Ralph Sawyer. The Director of the Institute of Science and Technology, for example, reports directly to Dr. Sawyer. Here I should also mention the University's Office of Research Administration, whose Director is Mr. Robert Burroughs, who will talk with you this afternoon. This office provides staff assistance to Dr. Sawyer, and services and assistance of many forms to the various research activities throughout the University. I imagine many of you know Mr. Burroughs and his colleagues, but perhaps in association with the former UMRI, the University of Michigan Research Institute. UMRI was the former name of the Office of Research Administration.

The total of the University's research activities is truly imposing. Measured in dollars, for example, the direct costs for research in the fiscal year ending in June of 1961 were in excess of $30,000,000 and will be larger this year. This compares to $5,000,000 in 1950 and $750,000 in 1940.

Over $13,000,000 of the research support came from the Department of Defense and more than $7,000,000 from other agencies of the federal government. With this support, the University topped the list of Department of Defense prime contract recipients among those educational institutions which do not operate federal facilities for the government (The Los Alamos Laboratories in New Mexico, for example, are managed and operated by the University of California). The University ranked fourth or fifth among the universities of the country both in the size of its total research program and in the research support received from the federal government.

Other sources of support, in order, were private foundations and associations, industry, endowment funds and State funds. Only a very small part of the research program is supported by funds provided by the State of Michigan, which is understandable: our State appropriations go to the support of the direct educational program, and are rapidly becoming inadequate even for this purpose.

The University's over-all research program covers nearly every conceivable field of interest and activity; it contributes importantly to the advance of knowledge on many fronts, to many aspects of the University's educational function, and to many vital matters of national and state welfare. It assists in attracting and retaining of a highly competent faculty, and is a necessity for the appropriate training of the research personnel who will staff our industries. Without it, the University would not be what it is, and without the outside support of the research program I am certain the State appropriation would be completely inadequate to the University's research functions.

I wish there were time for you to hear about many of the parts of the over-all program in some detail, but there isn't. Let me, however, take this opportunity to tell you something of our Institute of Science and Technology, which is sponsoring this meeting.

I believe you will find we play an important, and in many ways, an unusual part in helping the University meet the challenges it faces these days for instruction, research, and public service in the area of engineering and science. I believe you will also find us an asset in the State of Michigan's program for meeting some of the economic challenges it faces, since one of the Institute's major missions has been established in response to the State's need for an expanded and diversified industrial base.

First, let me give you some indication of the magnitude of the Institute's activities. Our staff of over 600 people makes up about 8% of the total staff of the University. Our annual research expenditures amount to nearly 10 million dollars. Of these some $9 million are obtained through cost-reimbursement contracts with governmental and industrial sponsors. These are contracts in which all University costs, direct and indirect, are borne by the sponsor; we call this our sponsored-research program. This year, we also have $900,000 of State support; I will try to show you later why these State funds represent a resource far more important than their portion of our total budget would indicate.

The Institute of today represents a merging of the purposes and the programs of what a year-and-a-half ago were two separate University organizations: one, the organization established under the name Institute of Science and Technology by means of State legislative appropriation in 1959--and the other the former Willow Run Laboratories, which contained the large-scale sponsored-research programs which have been carried on by the University at the Willow Run Airport since the end of World War II. Incidentally, an earlier name of the Willow Run activity was the Michigan Aeronautical Research Center—the initials of which are the MARC of the present BOMARC air-defense missile system, which you have probably read about. The development of this missile was, in the initial stages, a collaborative venture between the Boeing Airplane Company and the University.

The establishment of the Institute in 1959 had as its basic aim the provision of a center to help strengthen the State's resources of science and technology, and to help focus them on the problem of enlarging Michigan's economic base through an increased research-based diversification of its industry.

The present Institute is a complex of many activities and it will be possible today to discuss it only in broad outline. First, I will tell you about the Institute's internal research organization, its staff and facilities, and the participation in our program of members of the teaching faculty and other research groups of the University. Then I will tell you a little about our sponsored research program, which is financed by governmental and industrial sponsors, and a little about our State-supported program, even though these two are not truly separate. In my discussion, I can perhaps at least imply how much the sponsored-research and the State-supported programs are interrelated and how they augment each other.

Our staff is made up of some 275 engineers and scientists, plus a supporting staff of about 350. These are grouped in 16 research units and in associated supporting service departments.

In engineering and the physical sciences we have research departments in radar, infrared, acoustics, seismics, solid-state physics, electronic countermeasures, operations research, information processing, sensory subsystems, and analog and digital computation. These, along with our Engineering Psychology Laboratory, are all units of the former Willow Run Laboratories. Our Great Lakes Research Division, formerly in the University's Graduate School, joined the Institute in 1960. We have a Biophysics Division in the organizational stage, and have just recently received the acceptance, as director of this division, of Dr. J. Lawrence Oncley, who is now a Professor at Harvard, a member of the National Academy of Sciences, and President of the Biophysical Society. We have recently established a Glacial Geology and Polar Research Laboratory. This has provided an administrative home for the research activities of Dr. James Zumberge of the Geology Department, who, as you may have read, was recently named President of the Grand Valley State College being established in the western part of the state.

One of our supporting units, that you may be surprised to find in a University, is our aircraft facility, which at this time maintains and operates a fleet of 8 government-furnished aircraft, which we use as flying laboratories. Somewhat like this, for our Great Lakes research program, we have just received funds to refit a 114-foot vessel for research and to build a 50-foot one. Almost all of our extensive equipment, incidentally, has been acquired from the federal government, as costs under our contracts.

Perhaps some statistics about the Institute staff will be interesting to you.

Of the 275 members of our research staff, some 60% have either master's or doctor's degrees at this time. About 50 of these 275 are working part-time toward their Ph.D's, and more than 50 others are working part-time toward their master's degrees. Many of our Ph.D candidates have work on our programs which is directly applicable to their doctoral dissertations; this is true of sponsored research throughout the University. In addition, nearly 100 members of our supporting staff are working part-time toward bachelor's degrees.

Another feature of our staff seems to me to be particularly appropriate and important to a large-scale research program conducted within a university: over one-half of our research staff has taught at the college level, with some 50 schools being represented in this teaching experience. A number of our research staff now teach on a one-course-a-semester or one-course-a-year basis, and many of them participate in the Engineering College's intensive summer courses for personnel from industry and government.

Indeed, a large-scale continuing research program such as ours provides an unusual opportunity for our University to attract capable scientists and engineers who like to teach a little, but who wish to emphasize research. There are today a good many members of our teaching faculties and of Michigan industry who first came into the University and the state through the research activities at Willow Run.

Many members of the University's teaching faculties, along with their own graduate students, are actively engaged in both the sponsored-research program and the State-supported program of the Institute. This, of course, greatly enhances the Institute's research capability. On the other hand, our full-time staff and our extensive facilities permit a concentration and a continuity of effort which enables the University to undertake, and members of the teaching faculty to participate in, research programs of both scientific interest and national importance on a scale beyond that readily possible for individual members or small groups of the teaching faculty. Furthermore, these large-scale programs have been, and cannot help but continue to be, important to the long-term industrial growth of the state.

Now let me turn briefly to our facilities.

The major portion of the Institute's research facilities is housed on the eastern edge of the Willow Run Airport, in a group of converted hangars and barracks that were part of the military activity associated with the Willow Run Bomber Plant during World War II. Our Engineering Psychology Laboratory and our Great Lakes Research Division are housed primarily on the Ann Arbor campus.

I feel certain that our program until recently has been limited by the amount of laboratory space we had available, but some recent developments will do much to alleviate this. You may have read, for example, that about a year ago the University acquired from the federal government the facilities of the former 30th Air Force Division, which are adjacent to our present Willow Run quarters. Moreover, construction has now begun on an Institute building on the North Campus; the building should be completed by the spring of next year. Both of these acquisitions should make it possible for us to take on an increased number of important programs. The North Campus building is being financed in part by $480,000 of matching funds from the National Institutes of Health of the federal government for the construction of a wing devoted to biophysical research.

Now let me tell you something of our sponsored-research program. At the present time, as I have said, this is proceeding at a 9-million-dollar-a-year rate, with about 45 cost-reimbursement contracts, sponsored primarily by the federal government and, in the main, related to national defense. One of these projects, which we call Project MICHIGAN, is currently operating at a 4-million-dollar-a-year rate, and has had a total funding of over 40 million dollars during its 9 years of operation. I will tell you a little more about this project later.

Our sponsored research may in one sense be termed "directed research" in that, with a few exceptions, the individual projects have their origins in particular needs of the sponsoring organizations. Thus our sponsored-research program contributes to areas of vital national interest such as combat surveillance and target acquisition, submarine detection, the detection and monitoring of underground nuclear explosions, air defense against missiles and manned aircraft, satellite instrumentation, civilian air traffic control, and many others.

In another view, however, our portfolio of projects make up continuing programs of activity in important scientific and technological areas. We select our projects both for the significance of the sponsor's problem and for the degree to which they will bring us into frontier areas of research and advanced technology. As a result, the activities that are necessary and appropriate to the accomplishment of our sponsors' goals also contribute directly to an advance of knowledge in engineering, physics, mathematics, psychology, and the like.

That the defense problems which we undertake are, at root, really problems in engineering and science is perhaps illustrated by the fact that well over half of the reports we generate under our security-classified defense contracts are themselves unclassified. As a result, much of our work is published in professional journals.

Now let me tell you a little about our Project MICHIGAN. In this project we represent the nation's primary research effort for advancing the Army's long-term capability in combat surveillance, and target acquisition. Formally stated, combat surveillance is the "continuous, all-weather, day-and-night systematic watch over the battle area to provide timely information for tactical ground operations." In simplified terms, the goal of the project might be called the development of technical aids, such as radar and infrared devices, which would prevent such situations as that of the Battle of the Bulge in World War II, when weeks of heavy ground fog in the Ardennes permitted the Germans to concentrate, undetected, the armored forces required for their spectacular and nearly successful breakthrough.

Project MICHIGAN presents a wide variety of activities ranging from fundamental research through applied research to the engineering development of advanced components and equipment. Here we are brought into the forefront of such fields as radar and infrared because of the Army's requirements for an all-weather, day-and-night capability for detecting and locating targets. We study the navigation-and-guidance problems of aerial vehicles because of the need for transport and control of airborne sensory devices. Applications of advanced data-processing-and-display techniques become necessary for the timely collation into useful information of the voluminous data which can be provided by such technical sensors as radar and infrared. Engineering psychology is introduced in the treatment of man-machine relations. And so on, through a long list.

In the short time we have, I can only begin to touch upon the many activities of Project MICHIGAN. There are two, however, that you might find particularly interesting and illustrative. (It just so happens that they are among our more prominent successes.)

One of the project's most notable contributions has been in the field of radar. Now known as the Michigan high-resolution radar system, in many quarters it has been called the most significant advance in airborne radar since World War II. Basically, it's a system which, when carried in an airplane flying at low altitude, can map a strip of terrain many miles wide and many miles off to the side of the airplane, without distortion and with a uniquely fine and detailed presentation of terrain detail.

The heart of this accomplishment was a true technological breakthrough, achieved by our radar staff: the creation and development of a unique data processor. This allowed us to implement our concept of "synthetic radar antennas." Thus we now can carry a very small antenna in an airplane which flies a straightline path, store the radar echoes returning from the ground being surveyed, and then--with this processor--effectively reconstruct the stored data into the equivalent of that from the great many antennas, hundreds of feet long, and with different focuses, which would be required to obtain the same performance with the use of conventional radar techniques.

The techniques of this unique data-processor, while first developed in the radar context, have already turned out to have exciting applications in a number of other areas. Therefore, we are now investigating the application of the same basic techniques to five entirely different and important problems associated with national defense, both under Project MICHIGAN and for four other sponsoring agencies. I would like you to recall this growth pattern later, when I discuss the inherent potentials of the use of State funds as "seed-money" for first-stage initial research.

Another interesting Project MICHIGAN program has been our work on masers. These are solid-state electronic devices with unusual capabilities as receivers or amplifiers of weak electromagnetic signals. Out of a program of basic physical research on the phenomena of electron spin-resonance, our solid-state physicists made the first demonstration of the remarkable properties of ruby as a maser material. Within a few months after their results were published, literally dozens of industrial and governmental laboratories throughout the country were engaged in extensive programs capitalizing upon this finding. The company making boules of synthetic ruby, for example, immediately began taking out full-page ads in the technical journals.

The reception and amplification of weak radio signals was and is an important problem to our Project MICHIGAN. Thus, in order to obtain field experience with masers, the Project built a field-model maser radiometer. In cooperation with the University's Astronomy Department, this was installed on the University's 85-foot radio-telescope at Peach Mountain. There the maser's truly remarkable sensitivity helped make possible the first unambiguous detection of the natural radio emissions from the planets Mercury and Saturn and from a planetary nebula.

Our work in the maser field has been broadened to include lasers, or optical masers, in which light is amplified. And for the National Science Foundation, we are now developing a much more sensitive maser radiometer for use in radio-telescopy. It is expected that this radiometer will come to the University for use on its 85-foot antenna.

Now let me mention just three more of our forty-five sponsored-research projects, similar to each other but different in kind from any I have mentioned previously. For the Department of Defense we are operating three national centers of information and analysis: in infrared technology, in the seismic detection of underground nuclear explosions, and in the basic radiation phenomena of intercontinental missiles that we must know more about for the development of air-defense systems. All three of these projects have their origins in essentially the same problem: the need for the timely and centralized collection, collation, analysis, and dissemination of the voluminous information being gathered by the hundreds of contractors engaged in these important fields for the federal government.

Let me end my discussion of our sponsored research with a brief indication that all our activities are not solid-state physics and the mathematics of data processing. We are now engaged in a flight measurement program in Greenland, and have recently completed several others in Arizona, one of which covered a large part of the mountain states. Not long ago, we had men camped in the mountains of Arizona for studies of electromagnetic-wave-propagation anomalies associated with airborne navigation systems, and last summer we carried out a program of core-drilling in the bottom of Lake Superior and are now planning another. We now have people at Cape Canaveral, and others have just returned from making seismic measurements of earthquakes in the western states. This program will later send them to the Philippines, to Turkey, to the Aleutian Islands, Chile, Japan, New Guinea, and elsewhere. And you may have read recently of Dr. Charles Swithinbank's activities in the Antarctic.

It's pretty clear that the tower isn't only ivory. And, as our President Hatcher said at the unveiling of our high-resolution radar system, in reference to the students that had participated in that program, "It certainly beats dishwashing as a way to work your way through college."

Now let me turn from our sponsored-research activities to the Institute program supported by legislative appropriation and aimed at strengthening the State's scientific and research resources.

As I describe some of our many activities under this program, you will note that the sponsored-research program I have just described, as well as the many other sponsored and unsponsored research activities of the University, all make important contributions to nearly all the objectives of our State-funded program, and as such are also important to the State's future economic well-being. In large part, it was this compatibility that made the merging of the sponsored-research activities of the Willow Run Laboratories into the new Institute very appropriate.

Sponsored research alone, however, by its very nature cannot provide all the capabilities necessary to strengthening the state's research base. Certain critical freedoms of action and exploration will generally be missing.

The sophistication of the concept of the State-funded program is very apparent to us in that it provides for the accomplishment of many important things for which other support cannot be obtained.

One of the key activities under State funds, for example, is the first-stage support, on a limited scale, of selected research programs in areas considered particularly promising to the State's future. This support is provided on a kind of "seed-money" or underwriting basis, and represents an investment with potential large-scale returns both in scientific advance and in eventual larger-scale support of the work from other sources. It is a fact of life that outside support is most difficult to obtain for the unrestricted initial exploration that is so important to scientific advance, and far easier to obtain for the enhancement or application of such advances.

There is another aspect to the Institute's support of research under State funds. With careful selection of sponsored-research projects, the interests of our sponsors will, of course, be completely compatible with the interests of our researchers. The converse, however, is often not true. The interests of the researcher often go beyond the objectives appropriate to the particular sponsoring agency. Even small amounts of State funds can go a long way in permitting aspects of a sponsored-research program to be exploited in areas not of interest to the present sponsor, but which hold high promise of being beneficial to science and the State. The data-processing technique I mentioned earlier might well prove a case in point.

Only a small portion of the State funds go into research carried out within our Institute itself, since our large sponsored program provides us with much flexibility. In the main, these state funds go to support projects in the engineering and science departments of our University and other schools of the state.

Closely related to the use of state funds for first-stage support of research is the provision of key research equipment and facilities for enhancing the research capability of the State. An example is the Institute's assistance in providing our College of Engineering with a new hypersonic wind tunnel and magneto-fluids laboratory, now among the most advanced facilities of their kinds in the country.

State funds are also used to release selected members of teaching faculties from their teaching duties, allowing them concentrated periods of research of a semester or two. Such appointments are, of course, made only with the concurrence of the teaching departments; these departments gain not only from the increased opportunity for research presented to their members, but also from the budget openings which enable them to invite visiting scholars to carry on the teaching activities normally performed by the appointee.

In our program of supporting and stimulating research, we also bring visiting scientists to Michigan for periods ranging from a few days to a semester or a year; these "scientists-in-residence" conduct research, hold seminars, give lectures, and meet with their colleagues throughout the State. Closely allied with this has been our lecture program which has, to date, supported six major lecture series and many individual lectures and conferences. The proceedings of two lecture series have already been published by the McGraw-Hill Book Company, and another set is now in press.

We also support a predoctoral and postdoctoral fellowship program, here and in the other schools of the State, to identify and encourage especially gifted young men, with the hope--not incidental--of keeping them here in Michigan.

In all these activities, emphasis is given to fields of research of high potential to the State's future economic well-being.

The foregoing State-supported activities are all essentially far-reaching attempts to make Michigan a more attractive center for the performance of advanced research and hence for research-based industry. As such, their pay-offs—like those of research itself—

will largely come over the longer term. Indeed, in more instances than not, the chain of cause and effect between the "seeding" activities of the Institute and the eventual benefits to the State's industrial base will, in retrospect, probably be difficult to discern.

Some of our other State-supported activities aim at meeting the purpose of industrial assistance in a more direct and tangible manner.

We are holding conferences such as this one, with various industrial groups of the State, to discuss their problems and the University's programs and capabilities, to see how industry can be helped to derive greater benefit from the University's research program and the State's many scientific and technological resources. Our State program continues to evolve as more information is obtained and the value of new approaches becomes apparent.

Under our sponsorship, in a cooperative effort among Institute personnel and people from the University's Departments of Industrial Engineering and Economics and the School of Business Administration, we are engaged in what might be termed a program of Industrial Development Research. You will hear more of this today. Part of this program is a study examining the recent changes in the Michigan economy, and where we stand compared with the country as a whole, along with projected future trends in industrial growth.

We are also examining the new-product-development capabilities of various sectors of Michigan industry, and are carrying on a study program designed to yield further understanding of the basic nature of the product-development process, in order to aid state firms in formulating policies for product development. We have also established an industrial liaison activity which is aimed at expanding the University's ability to transmit the results of its research to industry, and in general to try to help Michigan industry make fuller use of our scientific and technological resources.

Before I call an end to my listing of some of the Institute's varied activities, I should certainly point out one area where we contribute very directly, and with no planned purpose, to the State's economy. This relates to the role of large-scale sponsored research programs such as ours as a very direct source of new industry, through the "spin-offs" in which researchers go into business for themselves. These have been markedly characteristic of the New England and California research and development complexes, and the research activities of the University have been no exception to this pattern. From the staffs of the Willow Run research activities and the sponsored-research programs of other units of the University, for example, came the people instrumental in establishing Ann Arbor's large Bendix Systems Division, the American Metal Products research division, the Strand Engineering Company, the newly-founded Trion

Instrument Company, and Conductron Corporation. I am certain we can look forward to an acceleration of this basically healthy process in the state in the years ahead. I, for one, think this snowball has really started to roll and grow.

It has been amply demonstrated that industry based on advances in technology will grow and flourish in an atmosphere of scientific education and research. In the East and the West, for example, around MIT and Harvard and Cal Tech and Stanford, tremendous complexes of industrial research and research-based industry have sprung up in a very short period, serving both the military and civilian sectors of the economy. I read the other day, for example, that the new electronics industry of New England now employs very nearly the same number of people as its textile industry.

It is not coincidence that the outstanding modern technological-industrial complexes of the East and West Coasts developed around great universities and technical institutes. Here were extensive ongoing programs of scientific research and technological advances and here were rich supplies of scientific skill and ingenuity. And, of critical importance, here were the stimulating atmospheres of creativity and innovation, the communities of scholars, and the intellectual and cultural environments to which key scientists were attracted.

The growth of these complexes demonstrates that scientists will go where there are communities of scientists, that contracts will be let where there is established skill, and that the advances of science are likely to have a particularly large economic impact in the areas where they are conceived.

There is not as yet a midwestern counterpart of these eastern and western complexes, but there will be. It should be here, in Michigan. We have a great deal going for us. We have the necessary and appropriate educational complex. We have a state of remarkable resources, and with a history of leadership. We appear to have everything that it takes. All that remains, it seems to me, is the work of concentrated and directed effort. Indeed, perhaps nearly all we need to do is to take greater advantage of what is already present and in being.

Our Institute is proud indeed of the increased opportunity to help this process that the support of the State has given it.

Once again, my best wishes for a fruitful and pleasant visit. Please come back, as a group and individually.

7

RESEARCH IN BUSINESS MANAGEMENT AND ECONOMICS

Alfred W. Swinyard

I am particularly pleased to have the opportunity to give you a brief view of the ways in which the University of Michigan can aid the machine-tool industry with its business and economic research problems. One reason is that the machine-tool industry has special significance in our economy and in the state. The other is that research in business management and economics at the University is on the threshold of a new and exciting period. The development of closer working relationships between the machine-tool industry and the University in the area of business and economic research will help us both achieve our individual, yet mutual, objectives and obligations.

I'm sure that each of you could document the importance of the machine-tool industry to our economy and to the state. The health of your industry reflects the health of the national economy. This is also true in Michigan, perhaps even more than we realize, for one out of every five machine-tool companies with sales over $1 million per year has its headquarters in Michigan. As a consequence, there are a lot of problems that require business and economic research in Michigan.

Your industry has all the usual management problems, plus a few special ones, such as the continued concentration of your industry, the trend towards broader product lines, wide fluctuations in sales and even wider fluctuations in profits, vulnerability to international developments, long product-life cycles, and major planning problems to capitalize on the technical advances being made in the laboratories. Business and economic research can significantly assist management in solving these problems.

Just as the character of research and development has been changing in your industry, so has the character of business research at the University been developing rapidly over the past few years. The individual creative scientist still plays his part, of course, but more and more research is the result of team effort--effort that draws on various fields of science. This means less and less research completed by the individual professor in his office and more and more research out in the field, where business firms and executives represent our laboratory. This, in turn, requires sponsorship of research--by foundations, industry or individuals.

You may well ask, "Why should the University do business research at all?" The answer will be found in the primary and essential objectives of any great university. It is generally agreed that there are at least three of these objectives. The most widely recognized is the dispersion of knowledge: the teaching and publication function. The second is the conservation of knowledge, the task entrusted to the libraries, museums, and other agencies for making the acquired knowledge readily available to those who need it. The third objective is extension of the boundaries of knowledge--the research function.

In the field of business we feel that research and teaching are interdependent. These two activities should overlap because they aid and stimulate each other. Experience shows that teaching is most meaningful when the person doing the teaching has an opportunity for extended research in his specialized field. The research obligations of the University are more than simply pushing back the frontiers of knowledge and accumulating new data. The research program must provide training for young investigators of promise. We might say that the research program is also a special aspect of the teaching function: it is a way of training researchers to carry on in business or public service.

The Board of Regents recognized business research as essential to an educational program serving the developing needs of the state and nation when the Graduate School of Business Administration was founded in 1924. This recognition was given formal support by the establishment of the Bureau of Business Research in 1925. At that time the Bureau of Business Research was specifically authorized by the Board of Regents to maintain continuous contact with business, promote research in business and applied economics, co-ordinate and facilitate faculty research, and publish research findings and classroom materials in order to enrich the teaching of the School.

Subsequent growth of the School and its research activities resulted in the creation of the Bureau of Industrial Relations in 1935, and the Program in International Business in 1961.

Several of the early research projects are now considered "classics," including the first study published by the School, The Life History of Automobiles, by Clare E. Griffin, issued in 1926. This pioneering study was followed in the next five years by research on such topics as employee suggestions systems, sales quotas, measures of business conditions in Michigan, industrial and commercial research, and the effect of foreign markets on the automobile industry

These early studies established a broad base to our research interests so that today we can say that we are interested in any project which will extend our knowledge of the organization, techniques, methods, and strategy which a business must have in order to survive and grow. The knowledge that is needed may be further defined by certain postulates about the conditions under which business has to set objectives, obtain satisfactory standards of performance, and achieve results, if it is to keep its position in our society. Five such postulates are:

First, a business requires an organization of human beings. Its parts must work together effectively and economically, and it must be capable of self-perpetuation.

Second, a business must be conducted to exist within the opportunities and restrictions of the current and future social, economic, and political climate.

Third, the specific purpose of business is economic in nature, and business must justify its existence through economic performance.

Fourth, business enterprise is unique in that it is the only major social institution designed to create change or to innovate. It must develop new technologies and new techniques in marketing, finance, and other functions.

Fifth, business enterprise is dependent upon profits adequate to meet the ultimate costs of its risks.

Basically, then, we are interested in and now doing research which will lead to better understanding or improved company performance in relation to any one of these fundamental areas essential to survival and growth: organization, adaptation of business to the changing competitive and economic situation, ways to achieve effective economic performance, the management of innovation and change, and methods of profit improvement. In addition to our interest in the problems encountered by individual companies, we are deeply concerned about the role of business in relation to the health of our state and national economy.

We have three units in the Graduate School of Business Administration carrying out a co-ordinated research program. The Bureau of Business Research acts as the research and service arm of the School in connection with all areas of business and applied economics. We co-ordinate our program with the specialized research units of the School and the University. The Bureau aids individual faculty members with their own research activity and conducts research projects by teams of specialists. Many of you are familiar with the study on Make-or-Buy Decisions in Tooling for Mass Production, by Paton and Dixon, which we published last year. Our current research projects include work on such topics as the growth requirements of the steel industry, measurement of advertising effectiveness, product planning and development, management factors contributing to the success or failure of small businesses, accounting for intercorporate investments, economics of consumer installment credit, and the demand for durable home furnishings.

The Bureau of Industrial Relations was established to promote a more adequate understanding of industrial relations through study, teaching, and research. Among their current research projects are studies of recruiting high-talent manpower, manpower planning and forecasting in industrial organizations, industrial practices and attitudes towards unionization of white-collar workers, and the organization and functioning of local labor-management councils. In addition, the Bureau of Industrial Relations makes a continuing analysis of the content of fifty labor union periodicals and publishes the Index to Labor Union Periodicals, as well as other special studies. The Bureau of Industrial Relations also has an active conference and seminar program for industrial relations and personnel specialists. So far this year the Bureau has had seven special two-day seminars for management personnel. Another seminar is being held next week on the subject of the management of engineers and scientists.

The Program in International Business was recently established to extend training and research in international trade, finance, and investment. Current projects involve problems encountered in the translation of foreign-currency financial statements into dollars, and the methods of handling the accounts of foreign subsidiaries in the financial statements. In addition, we now have a man in the Far East studying how the social security system and medical care will affect business in the Philippines, Australia, and New Zealand. This study will also include several leading Western European countries.

Although the Department of Economics does not have a formal research agency, their faculty is active in research work as individuals and in co-operation with other research groups. Faculty members of the Department of Economics and other units of the University participate in the program of the Graduate School of Business Administration, thus making the broad resources of the University available for research in business and economics. Last year expenditures on these programs amounted to approximately \$1 million, of which about one-third was devoted to business research and two-thirds to special conferences and instructional programs for business. A relatively small share of this effort is supported by state funds; most of it is dependent on foundations, the federal government, and industry. It should be mentioned also that several times this amount is being spent on research in the behavioral sciences--much of which is of significant interest to business.

We should note that as research units of a state institution we are not acting as management consultants. In general, we operate under the policies outlined by Mr. Burroughs. We undertake research that will be of general interest to broad business groups or industries, seeking to add to the fund of knowledge available and to develop improved techniques. We are, however, happy to discuss your individual problems and suggest ways in which you might solve them. We are never too busy for this. If you require extended consulting we may be able to help you locate individuals or firms particularly well qualified for the assignment; and if special research is required, we would be happy to discuss the nature of the research task and the approach and methods of solution. Since your individual problems frequently require basic research or the development of new approaches, we can very often aid you in your special problem and also make a contribution to our own research and teaching program. We may find that the results or the techniques themselves will make a significant contribution to our research and teaching program, and in that case we will be happy to discuss ways in which we can undertake the required study.

If we are to help you at all, the first requirement is that we make contact and get to know each other better. One means of maintaining a better line of communication is to read our little bi-monthly publication entitled Michigan Business Review. This contains articles of current interest to business executives and frequently summarizes the results of our research investigations. It also announces special publications of the School. We would be happy to have each one of you receive this. If you are not now on the mailing list, I invite you to give me your card and I'll see that you begin receiving it regularly.

Inst. of Science and Technology, U. of Mich., Ann Arbor PROCEEDINGS OF THE MACHINE TOOL CONFERENCE, March 28, 29, 1962, ed. by Clark E. Chastain. Industrial Development Research Program. June 62. Illus., tables, refs. included.
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